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**Trajectories of Legitimate Peripheral Participation:
Ethnographic Case Studies of Learning Ecology**

by

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DOCTOR OF PHILOSOPHY

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We accept this dissertation as conforming
to the required standard

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ABSTRACT

Current reform documents in education call for elementary and high school students to engage in "authentic" scientific practices. In the past several years a number of authors have suggested that science education research and curriculum development could benefit from insights gained by research in the social studies of science that documents and theorizes science as it is actually done. Yet, although practices of laboratory science are well understood and provide a foundation from which educational practices could be drawn, little is known about the practices of the science disciplines which deal with field research and how people are enculturated into those practices. This dissertation is constituted by a series of research papers on different (although inter-related) topics, in which I examine the enculturation into the practices of field ecology and the world-view that is associated with that enculturation. To better understand the practices of field ecology and how they develop, I conducted several projects : (i) a video ethnography of a second-year university ecology class and observations on research experiences undergraduates experience, (ii) ethnographic research with ecologists conducting field research; (iii) observations of graduate student and professional ecologists as they participated in conferences, engaged in interaction in their laboratory and social settings, and presented/discussed their findings in various settings; (iv) interviews with graduate student and professional ecologists discussing their field research experiences; (v) videotaped interviews with practicing researchers and under/graduate science and non-science students as they interpreted various ecology-related inscriptions; (vi) an analysis of the inscriptions and textual information present in the various texts (textbooks and journals) used to teach students about ecology; and, (vii) observations of elementary school students engaged in practices congruent with those of field ecologists.

Collectively, these studies suggest that the way in which undergraduate students are taught about disciplines such as ecology which involve field research—generally lectures and structured laboratory research investigations—does not well prepare them to enact the practices common to research in the discipline such as designing and conducting research projects, summarizing and interpreting data in graphs, and making scientific knowledge claims. In addition, the formal texts (textbooks, lectures, and journal articles) used to enculturate students into disciplinary concerns and practices develop in students a reductionist, anthropocentric view of nature as opposed to the holistic view which ecology ostensibly represents. Story-telling within the community was revealed as an important mechanism by which field research methods, almost unmentioned in the formal texts of the discipline, are learned and the community of ecologists established and maintained.

These findings have implications for how we prepare student teachers to teach science, for merely encouraging them to take undergraduate science courses will develop attitudes about nature and approaches to teaching which are perhaps undesirable. On the basis of the study reported, I conclude that both teacher education and science curricula would be best served by engaging participants (either student teachers or public school students) in long-term research projects whose conclusions they can present and defend to peers and instructors in their education program. This would need to be coupled with a critically reflective component which encouraged these participants to examine the assumptions and implicit judgements made in the conduct of their work. By engaging in such a process students will learn about scientific practices and concepts as well as about the socially-mediated nature of scientific communities and knowledge.

Examiners:

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Chapter 1:

Introduction: Personal, theoretical, and analytical commitments

Recent science and math curriculum reform documents (e.g., AAAS, 1993; NCTM, 1989) have called for the enacting of “authentic” practices in science and mathematics classrooms. Researchers in education have drawn on existing ethnographic studies of scientists (e.g., Lynch, 1985; Latour & Woolgar, 1986; Traweek, 1988) to inform their analyses of student learning in these “authentic” settings and to make recommendations for classroom practices that can meet these proposals (e.g., Roth & McGinn, 1997; Roth, McGinn, & Bowen, 1996). However, these ethnographic studies of scientists and science rarely focus on either the enculturation of scientists-in-training or on field scientists (e.g., biologists, ecologists) and instead focus mostly on experienced scientists conducting research in laboratory environments. Thus, little is known about the trajectory of enculturation from middle-school science to the practices of professional field research—information potentially valuable for the design of classroom science programs. The research presented in this dissertation is intended to address this shortcoming in the sociology of science literature.

The conceptual underpinning of this thesis is the notion of human knowing as practice. Practice theories are deeply grounded in phenomenological scholarship that focuses on how people cope in and with their everyday worlds. Practices enacted by experienced researchers in ecology can be thought of as representing core practices; here, the practices are the identifying characteristics of the core community so that the two, core community and core practices are mutually constitutive. Scientists constitute the core community, teachers and university students are more peripheral to the core community, and high school and middle school students are even further away from the core practices (usually). We can then conceptualize students’ learning in terms of a trajectory along which they increasingly participate, in legitimate peripheral ways, in the practices of the core science. The degree of legitimate peripherality of beginners who are enculturated towards the core practices is determined by the degree of overlap between their own practices and those of

the target community (in this case, field ecologists). Communities of practice with their core and peripheries constitute the conceptual terrain (map) of this study and *legitimate peripheral participation* (Lave & Wenger, 1991) constitutes the trajectories of individuals and groups as they move through this terrain. Each study in this thesis concerns a particular issue along this trajectory, from university-level science education to Ph.D. students, and professional scientific practice.

Specifically, this thesis is about ecology as a set of enacted practices which ultimately come to constitute the concerns, linguistic tools, and conceptual claims of the discipline. All of the studies in this dissertation are concerned with how a disciplines practices are enacted, how people learn those practices to become practitioners, and what type of obstacles they face when doing so. In this dissertation there are five pairs of chapters, each of which is concerned with one or more of the following: practices of people on the trajectory towards the core community (conducting research and interpreting graphs), obstacles people face in moving further towards the practices of the core community (which are related to breakdowns they experience), the tacit background assumptions people adopt as they move towards those core practices (such as reductionist world-views), and situations which facilitate peoples development towards becoming members of the core community (e.g., story-telling). The final two chapters are concerned with the pedagogical implications of the previous chapters for the science education programs designed for middle- and high-school biology classes.

This chapter lays out the methodological and theoretical foundations of the ethnographic research conducted to address this issue. First, I provide an autobiographical overview of my background in biology, sociology, and education as these experiences inform my theoretical and analytic interests. Then, a discussion of the literature on graphing, sociocultural theory, conducting ethnographic research, and analysis of qualitative data is conducted to provide an entry into the analyses found in the following papers. A short

description of each of the research projects from which the papers are drawn is also provided.

Personal Beginnings

The research that constitutes my dissertation is strongly rooted in my academic and personal history in the fifteen years before I started doing that research work. An understanding of my personal trajectory through science, sociology, and education is central to appreciating the ethnographic research; for the questions I asked, the research I engaged in, and my analytic framework are interpenetrated with my history of engaging in these domains. Thus, a brief autobiography of the events leading up to these projects is necessary before the theoretical foundations are established.

I spent most of a decade becoming a biologist, first at the undergraduate level, then through engaging in field research work, and then by completing a graduate degree. My academic success as an undergraduate was reasonable—I was often comfortably in the middle of the class in the early years, and then as the course material became less and less mimetic and more and more analytic I began to have more success in my program. My course assessments dealt little with writing essays or conducting any type of research which I designed, analysed, and presented (although in my program there were more occurrences of this than in many others) and mostly with written exams—which I remember as hand-cramping races during which I threw as much information as possible at the exam booklets in two short hours. These exams also became less regurgitative and more analytical as the program progressed.

When I completed my undergraduate degree I worked as a field assistant on numerous research projects. These projects included field work with humpback whales, right whales, harbour porpoises, manatees, bottlenose dolphins, harbour seals, Atlantic puffins, and various invertebrates and fishes in several geographic and research settings. The research involved several different domains including ecology, marine pollution, animal behaviour,

and environmental concerns (often combining several or all of these). Reflecting on those experiences, I now find it remarkable how little most of my undergraduate work had to do with the work I did in those field projects.

As part of several of these research projects I gave public talks and presentations, which I often found frustrating because what I considered important and interesting about those projects—particularly from an environmentalist perspective—was often difficult to communicate to those who attended these talks. It is from these roots that my interest in science education arose for until that point my own academic history had not provided me an appreciation of the views towards nature and animals broadly held in the public eye.

I decided that as a biologist I would have little impact on solving the environmental and ecological problems I perceived concluding that perhaps by teaching I could more effectively address them—and so I obtained my Bachelors of Education degree, sought a job, and began teaching middle school science. My initial classes revolved around themes that ran for months and involved my students in conducting series of activities. In other words, I tried to structure my classes so that they were analogous to the (enjoyable) experiences I had had as a working field researcher.

Michael Roth expressed interest in doing research in my grade 8 classes and I eagerly participated in the process, especially when I began to realize that how I taught my science classes was often much different from the approaches used by other science teachers. In the second year of my teaching I had also become interested in sociological aspects of the schools and classes with which I was working and I began an MA in Sociology. The work with Michael Roth during which I began to read some of the work in social studies of science and my own reading in sociology for my MA were synergistic—I started becoming interested in learning and student engagement in my classes from a sociological perspective.

Out of this beginning came my interest in inscriptions (e.g., graphs, maps, tables, etc.) and interactions between students in my classroom as they negotiated with each other about the various scientific claims and statements they had made in their reports. This initial project with Michael Roth has explicitly informed much of my doctoral research as student work (written and inscriptions) from that time has formed the basis for part of the work with inscriptions I have done with university students and researchers. Some of the earlier work using these inscriptions (e.g., Roth, McGinn & Bowen, 1998) reported that people with science degrees engaged in interpretative practices similar to those of the grade eight students but that they actually used less abstract (i.e., less advanced) representations than did the grade eight students. The dissertation research includes an extension of this work examining graph interpretation practices of pre-service elementary teachers, post-baccalaureate science students, and professional researchers from various science disciplines. An ethnographic study of ecologists and semiotic analyses of their work (and those of others) in several settings complement the research on inscriptions.

Theoretical Frame

Becoming enculturated into a discipline involves becoming enculturated into the ritualistic behaviours of that discipline. These behaviours often involve both structural/social components (i.e., the “heroes” of the field, roles of instructors and graduate students, etc.) and procedural components (i.e., how research is done, how interpretations are conducted, which claims follow from which data, etc.), which are inextricably intertwined. My middle-school classes emphasised scaffolding students so that they appropriated the material and linguistic tools of science, especially inscriptions, as part of constructing scientific claims. Students in my classes learned to use graphs as tools to construct relationships between variables so that predictions could be made from them (i.e., using scatter plots) as opposed to what I observed in the science, social studies, geography, etc. classrooms of my peers in which graphs were used only to show what was

measured (i.e., using histograms and bar graphs). My students developed considerable competency at doing science investigations because of the focus on inscriptions and independent research projects, but I felt that I needed a better understanding of the development of competencies at these tasks by professional scientists to better design curricula for my classrooms—another influence on my doctoral research.

Use of Graphs in Science Research and Education

Laboratory studies point to generating and interpreting inscriptions as the central activity of scientists (Latour & Woolgar, 1986; Lynch, 1985). Graphs are probably the most important of scientists' inscriptions because they afford easily readable representations of continuous covariation (Bastide, 1990; Lemke, 1998). Schank (1993/1994) listed graphing—including producing, reading, and critiquing graphs—as one of the seven most important skills of a professional biologist. Learning to produce, read, and critique graphs should therefore be an important ingredient of learning about science. However, there is some evidence that even college graduates with BSc and MSc degrees by and large have not developed the competence to use graphs in contexts where scientists employ them by default (Roth, McGinn, & Bowen, 1998).

Research conducted within the information-processing paradigm, which is that which is generally adopted to study students' deficiencies in graphing (Leinhardt, Zaslavsky, & Stein, 1990), shows that few students arrive at the normative interpretations of graphs that researchers hold as referents for student-generated solutions (e.g., Berg & Smith, 1994; Preece & Janvier, 1992). Thus, students are frequently said to have made scaling errors or exhibit iconic confusion and slope/height confusion (Leinhardt et al., 1990). However, the problem with adopting information-processing perspectives is that they easily lead to the conclusion that some individuals have innate problems learning graphing that derive from their mental hardware; such as having mental deficiencies or lacking mental tools (Hall, 1996). For example, it has been claimed that many students “do not have the mental tools

to engage in a high level construction or interpretation of graphs” (Berg & Smith, 1994, p. 549). Subjects are also said to have “deficient logical thinking abilities” such as spatial thinking and proportional reasoning (Berg & Smith, 1994), inferior domain-specific skills such as drawing (Lowe, 1993), or lower ability for adequately co-ordinating text and graphic information (Schnotz, Piccard, & Hron, 1993).

As a classroom teacher I found this information-processing framework to be little help in designing instruction so that all students could benefit. On the basis of studies on the development of graphing competence (e.g., Roth, 1996) and sociological studies of scientific (and other) practices (e.g., Lynch, 1985; Lave & Wenger, 1991), I began to frame my understanding of individuals engaging in solving a ‘problem’ in terms of a social practice perspective. Accordingly, my studies of graphing-related knowledge assume that ‘how-to-do/use a graph’ is not procedural information to be transferred to students’ heads but rather focuses on degrees of increasing participation in purposeful and competent graphing practices.

One study by Roth (1996) provided an explanation for student difficulties with graphing which did not rely on “cognitive problems” as explanatory resources. In this paper he framed the construction of graphs by students within a social practice perspective—they developed their graphing skills as they apprenticed towards successfully generating and translating multiple inscriptions, rather than viewing them as drawing on skills that reside in their heads. In this framework then, a lack of experience and opportunities to participate in graph-related activities are the major sources of students’ underdeveloped practices.

Interpreting graphs is often difficult for newcomers because a large number of representation practices are involved. For example, at each step of generating and translating inscriptions the existing ontological gap between two inscriptions has to be bridged, while at the same time the distance to their referent in nature is increased (Latour, 1993). During

interpretations people have to reverse the process and re-construct natural environments for which graphs could be viable representations. However, the relationship between two inscriptions, or between an inscription and a natural phenomenon, is always arbitrary and exists only because representing is a social practice. The reconstruction of such a natural phenomenon is therefore underdetermined, and there are potentially many situations to which a graph can be related. Unless students have sufficiently participated in constructing graphs as a social practice, and therefore have experience at bridging those ontological gaps themselves, they are unlikely to arrive at canonical interpretations for the meaning of the graph does not lie “in” the graph, but is constituted from the meanings such graphs have in the community in which they are used (Pea, 1993).

An information-processing analysis differs from a social practice perspective in that it is focused on information, its long-term storage, processing in short-term memory, and participants’ capacities for transforming information in their minds. Changing the theoretical framework for studying activities requires changing the ontology for the domain of interest. Within a social practice framework the ontology for graph interpretation used by the information-processing perspective is inappropriate—a social practice framework requires a new and different ontology.

The Nature of Social Practice

When looking at social practice it is helpful to have a theoretical framework or “lens” to guide interpretation of your observations. The guiding lens for analyses of social practice should examine standard practices, material and linguistic resources, sets of breakdowns, and sets of ongoing concerns (Denning & Dargan, 1996). These different components constitute a ‘map,’ referred to as the ontology of the domain, and provide a framework to help guide interpretations. That is, ontologies constitute conceptual frames for interpreting recurrent actions in a particular domain (see Winograd & Flores, 1987). Analysts who

work from a social practice approach are primarily concerned with the following five components of social practices:

- Sets of ongoing concerns of community members which includes common missions, interests, and fears. For example, theoretical ecologists and physicists are concerned with modelling aspects related to a phenomenon; field ecologists' may be concerned with managing species for commercial exploitation or conservation issues about that species.
- Standard practices enacted by members of a particular community so that the characteristic activities of the domain can be completed. In ecology, these include designing research for the purposes of collecting data, summarising the data, producing graphs, and drawing conclusions. Other activities engaged in by ecologists include, reading books that include graphs, writing articles in which graphs are used as evidence, interpreting and critiquing graphs that other ecologists have produced, and transforming and scaling graphs so that they support the propositions of the main text. Engaging in interpretative practices such that one reaches (discipline-specific) canonical interpretations may also be considered a standardized practice.
- Ready-to-hand material resources, such as tools and equipment, that members use as part of their standard practices; a tool is ready-to-hand if a member uses it transparently, focusing on the task rather than the tool. Related to ecology, such resources include graphing (with its embedded resources of labels, units, and scales), and mathematical, statistical, and other software that allows the production and manipulation of data and graphs. On the other hand, in ecology tools are often appropriated and modified from other uses so that they can be best used for the field project at hand (Nutch, 1996).
- Linguistic resources that members use to make distinctions important to competent and efficient activities of the field. Among linguistic distinctions in ecology belong: differences between population size and population density, and; birth rate and death

rates as functions of population density. In graphing, an example of such a distinction would be the difference between maximum value of a function and its slope. Acronyms are also important in ecology, such as MSY (maximum sustainable yield) and ESS (evolutionary stable strategy).

- Breakdowns are interruptions of standard practices and slow-down of an activity's progress that evolve from the breaking and absence of tools or changing of familiar contexts. Breakdowns can occur, for example: (a) when people do not command linguistic resources necessary to make the distinctions important to scientists; (b) when resources that are necessary for interpretation do not exist in graphs; and (c) when the tools (graphing calculator, modeling software) normally available for doing certain activities are absent or do not work. Stereotypic breakdowns can occur when members of one domain look at the work of another (for instance, when physicists interpret the work of ecologists).

This conceptual frame has been shown to be useful for investigating activities in the workplace, designing computer software, and analysing expert systems (Coyne, 1995; Dreyfus, 1995; Winograd, 1996). These five foci are also, although not necessarily explicitly, part of the focus of ethnographic research and subsequent analyses of its findings.

Practice Theory

Practice theory is a term used to refer to approaches to studying learning by examining the social practices and cultural productions in which a particular community engages (e.g., Bourdieu, 1977; Holland & Eisenhart, 1990), and is thus related to the ontological map detailed above. Cognition in these settings is viewed as being a dialectic between persons acting and the settings in which their activities occur such that agent, activity, and world are mutually constitutive—cognition does not just lie in the heads of individuals. By taking a focus on 'everyday' practices and how these generate meaning systems this approach is

also related to learning-in-practice or ‘apprenticeship’ which assumes that the processes of learning and understanding are socially and culturally constituted.

In learning settings guided by such perspectives, students (or apprentices) learn to engage in the concerns, practices, tool-use and linguistic distinctions of a discipline by engaging in those activities with “old-timers” (Lave & Wenger, 1991) who do that work well. By participating at first in legitimate peripheral activities (ibid.) and then more central activities newcomers progress on the trajectory to becoming old-timers who now themselves engage in the stereotypical practices of a discipline. Ethnographic studies of various *communities of practice* into which newcomers are enculturated resulted in a theory of situated learning focused on the content and organisation of activities over time (Lave & Wenger, 1991). This work described how local practices are embedded within the (socio)historical practices of the discipline and do not exist in isolation—it is not the activities of the current practitioners alone which are being learnt, but their own practices embedded in the histories of what they themselves learned. The concept of ‘cultural reproduction’ implies the learning and re-enactment of static practices; but this clearly is not all that is happening in science, for practices evolve and change. Practice theory permits examination of the cultural reproduction of current practices and how changes in those have, and will, occur(red) over time.

Two practice theorists, Margaret Eisenhart and Jan Nesper, focused on the reproduction of cultural practices in science in their study of the enculturation of newcomers to practices of environmental biology and physics. Eisenhart (1996) examined how individuals constructed the meaning of the term “scientist” in a university environmental biology program (EB); she did this again when the individuals from the same program (subsequently) worked for a “conservation corporation” (CC). She reported that there were different constructions of what it meant to be a scientist in those different settings and that this was related to the tasks in which the individuals were engaged. These

were in contrast to the construction of “scientist” reported by Nespor (1990) in his examination of an undergraduate physics program. In the EB program students were encouraged to deal with “real world” environmental problems, in contrast to the theoretical, “abstract” problems dealt with by the physics students. In the latter program, students were enculturated into a view that science was objective and removed from social interactions—physics scientists were portrayed as rational and open-minded. Thus, Eisenhart sees that the EB program is an “institutional dare to the hegemony of laboratory science” (p. 175) placing its science in the midst of the political and social issues that the physics program enculturates its students away from. In addition, the EB program encourages its students to make extra-academic social contacts with field practitioners, again unlike the physics program. In the physics program, students learned to replicate the traditional problem solving practices by (re-)solving problems based on the theoretical and experimental findings of the ‘heroes’ of physics. In the environmental biology program students learned to spend their time working with others on contemporary environmental problems. In their participation in these different activities students were being encouraged to adopt the concerns and practices of these respective disciplines—the cultural reproduction of disciplines is important to maintain their culturally respective roles. For instance, this education of physicists provides for aspects of social control in the military and energy companies which makes them impervious to local needs or objections (Nespor, 1990)—the very social pressures to which EB trained workers are expected to attend.

Research Projects

Using ethnographic research methods, the research discussed in this dissertation applies sociocultural perspectives of learning and community participation/membership, and the ontological map detailed above, to examine the ‘everyday’ research work done by ecologists and the enculturation of newcomers to those practices. To better understand the trajectory from being an inexperienced ecologist to being a competent field researcher who

can conduct research and use inscriptions several different ethnographic projects were engaged in. A brief description of each of these endeavours precedes the discussion of the methodological/analytic framework.

1. Video ethnography in a second-year ecology course: All lectures and seminars of a second-year university ecology course were videotaped. Interviews were conducted with students, the teaching assistant, and the professor. Student study groups were also videotaped. Other artefacts included copies of exams, notebooks, and assignments submitted by the students and ethnographic field notes recorded at the end of each encounter with students or instructors.

2. Field ethnography with ecologists conducting research: Four weeks were spent participating as a field assistant with ecologists engaged in research projects in the interior of British Columbia. Videotape records were kept of field and laboratory practices and audiotaped interviews and records of conversations were recorded. Other artifacts included: photocopies of field notes kept by the ecologists; hundreds of annotated digital 'photographs'; ethnographic, analytic, and autobiographical field notes; interpretative interviews over inscriptions, and; other written notes preceding and following the field exercise supplied by the field ecologists.

3. Graph Interpretation Interviews: Over two dozen individuals participated in interviews during which they provided interpretations of several different types of inscriptions. These individuals had varied backgrounds, ranging from being second year science students to possessing a PhD and having extensive field research experience. In many cases, these participants also provided interpretations of graphs they had used in their own research.

4. Observations of ecologists conducting field projects with elementary-level students: Field ecologists were observed and videotaped teaching middle-school students how to conduct aquatic ecology research. Videotaped episodes included field-sampling methods

(e.g., using D-nets and Serber samplers), identification of specimens, and proper data recording and summary techniques.

5. Participation in an ecology field exercise with second-year ecology students: I acted as a participant observer on a second-year ecology field research project. Ethnographic field notes, audio-taped conversations, a copy of a completed assignment, and comments by several student informants constitute the database.

6. Attending ecology conferences, symposia, and social functions: I attended over one dozen ecology conferences and symposia. Ethnographic notes were kept of use of inscriptions, participant comments and presentations, and of 'structures' of these formal presentations. Some talks were audio-recorded and several were video-recorded as well. Over three years I attended countless social engagements including coffee, lunches, after-hours socialising, parties at homes, and other such engagements with from one to dozens of ecologists. Ethnographic notes were recorded during or after these activities. These interactions often led to participation in other formal aspects of this research (such as field participation or interpretative interviews over graphs).

7. Field research projects with pre-service secondary science teachers: Pre-service secondary science teachers conducted mini-field research projects that were analyzed for use of inscriptions and structure of arguments (These participants also provided interpretations of inscriptions).

8. Interviews with ecologists about their field research experiences: Audio-taped interviews were conducted with over one dozen ecologists about their field research experiences and how they came to learn about their discipline.

Methodological Frame

Sociocultural studies of learning move from the individual as the unit of analysis towards considering the systems of individuals—in social, cultural, and technological settings—as units of analysis. In so doing, they adopt an ethnographic research

perspective, for “communities of practice are connected by more than their ostensible tasks. They are bound by intricate, socially constructed webs of belief, which are essential to understanding what they do” (Geertz, 1983). Ethnographic studies are concerned primarily with understanding the perspective of the participants in the community focusing on: language, concepts, categories, practices, rules, beliefs, initiatory rites, creation myths, rituals, power relations, habits, oral traditions, values, meaning, emotional reactions, and, evaluations by members (see Barrett, 1996; Emerson, Fretz, & Shaw, 1995; Lave & Kvale, 1995; Sanders, 1998; van Maanen, 1988).

Doing Ethnography

Traditionally, anthropological work studying these features of a community has involved a non-initiate joining or attending a foreign community and observing their practices over a considerable period of time. For instance, Jean Lave engaged in traditional ethnographic work when she spent months in Liberia observing the apprenticeship practices of Vai tailors (see Lave & Kvale, 1995; Lave & Wenger, 1991). Such an approach was traditionally used, in part, to distance the observer from the process being observed so that no cultural biases were embedded in the observations and subsequent analyses. This approach was considered to offer the advantage that the anthropologist only had to guard against newly adopting the ‘native’ standpoint, undoubtedly easier than ‘stepping away’ from already having that viewpoint. Still, fieldworkers were cautioned about “going native”—a term arising, no doubt, from the historical origins of anthropological research which had western social scientists viewing the community practices of non-western, or “native,” cultures in so-called primitive countries.

There were exceptions to that approach. The Chicago School approach to anthropology, developed in the 1920’s, involved studying communities in which one was already a member. However this approach fell into disfavour and was infrequently used for much of the last sixty years. Of late, some ethnographic researchers have returned to

conducting “auto-ethnographies” of communities in which they had previously been members. For instance, as an active member of the community Hayano (1982) studied California poker palaces and players, Orr (1990) studied the community of photocopier repair technicians having formerly been a technician himself (although not with photocopiers), and Barrett (1996) writes about returning decades later to study the small farming community in which he was raised. Although there is a definite need to guard against re-adopting the community members’ perspectives when we ethnographers conduct research and analysis, auto-ethnography offers several advantages to doing ethnographic field research. Lave describes spending many months just getting to know the tailors and the community well enough that she could begin her research (Lave & Kvale, 1995). Barrett reports, however, that having previously lived in the community he was studying offered the advantage of him being able to establish a more rapid rapport with the community members and that it also meant that he “was in possession of information that would have taken an outsider years to accumulate. In a sense, in the study of Paradise, I was my own informant” (Barrett, 1996, p. 189). He goes on to discuss other advantages of ethnographies on one’s own community such as appreciating nuances of linguistic distinctions and non-verbal communications, and that one is less likely to construct misleading stereotypes of people (p. 201). Clearly, conducting auto-ethnography offers advantages to the researcher unavailable when studying a community with which one is completely unfamiliar.

Apprenticeship as Method

Having a researcher act as a participant observer in a domain about which they had little or no experience before can be viewed as a form of apprenticeship. Such an approach can have considerable value because actually participating in the community as a member can provide insights otherwise unavailable. This research approach, often used in anthropological studies, adds another dimension to the observations made by the

researcher. Apart from the field notes of observations, notes of interviews with community members, and analytical notes made about those records, engaging in the community practices offers the researcher insights into those practices from an embodied perspective. Thus, the enculturation of newcomers into those practices can be examined in ways unavailable to the non-member, non-participatory perspective.

Using engagement in an apprenticeship as a field research method offers several advantages allowing the anthropologist to learn cultural and technical skills while at the same time having a minimal impact on the social system while the anthropologists is the focus of socialisation and education (Coy, 1989). Apprenticeships are particularly useful in understanding the aesthetics and technical aspects of craft production, however apprenticing can occur in areas other than the production of goods. Jordan (1989) studied Mayan midwives in part by apprenticing to become one. Young Mayan women often ‘absorb’ how to be a midwife, especially if they grew up in a family with one, in the process of growing up and being involved in a community with them. Despite not having that background, Jordan found that it was difficult afterwards to provide details of exactly how she was taught—whatever instruction she received came from participating with and assisting a midwife doing her job rather than her being explicitly “taught” how to be a midwife. In the community stories about difficult births and prenatal care related amongst adults are overheard first as children, and then later as they apprentice. It is usually only after having borne children themselves that a decision is made to become a midwife. Their trajectory from this point is an example of legitimate peripheral participation (Lave & Wenger, 1991) as they move from doing initially peripheral (although useful and necessary) tasks to finally conducting the most important tasks.

In many respects, this process is not dissimilar to the one described for particle physicists as graduate students learn to appropriate their practices and become a member of their community (Traweek, 1988). In the initial stages (e.g., undergraduate education) the

accumulation of a large body of “facts”, not embodied and lived experience as with the Mayan midwives, is considered most important. However, later in graduate school, as the craft/experimental aspect of working in the community becomes more central to its practices, students begin to participate in the tool-based practices of the discipline by “dismantling, repairing, and rebuilding” (Traweek, 1988, p. 82) pieces of malfunctioning equipment. Only by demonstrating competency with research tools at this level are graduate students allowed to proceed to working with functioning equipment, and later after that to plan and conduct experiments of their own.

Participating as an apprentice in settings such as these also permits the researcher to experience aspects of being a “midwife” or a physicist or a photocopier repair technician that would otherwise be unattainable. For instance, Coy (1989) developed an understanding of learning to hammer hot, heated metal that might well have been beyond simple observation or questions in interviews. In his apprenticeship as he hammered heated metal into rough shape he reported that he developed a “healthy respect” for the “hot scale” that fly from a piece of metal as it is beaten. Coy claimed he became accustomed to this, but also described learning to make his hammer blows such that he “made less of a mess” of himself. This ethnographic work as an apprentice revealed nuances of tool-related activities and better understandings of social relations, either of which might otherwise have been unattainable, a conclusion Coy himself reached.

This type of apprenticing into understanding a discipline’s practices is a remarkably different process than that in which students in western schools are mostly involved in. Here, students traditionally learn about tasks by reading about them or having somebody tell them about them, not by doing them. The understanding that arises from studies of apprenticeships offers considerable insights into approaches to education and underlies many current analyses of schooling. Studies of students engaging in forms of cognitive and tool-based apprenticeships in the practices of science suggest that they experience

considerable benefits as regards their understanding of the conceptual claims of science (see Bleicher, 1996; Roth & Bowen, 1993, 1994, 1995). Studies of pre-service teachers learning about science teaching in a similar form of apprenticeship (i.e., Roth et al, 1999) also suggests that an “apprenticing” approach offers considerable advantages over traditional forms of enculturating teachers to the practices of teaching science.

Tools of Ethnographic Work

Ethnographic work was traditionally conducted by observing or participating in activities in the field and keeping extensive, cross-indexed notes and ongoing analyses as one conducted the fieldwork. Usually, one researcher did this work as s/he lived with or worked in the community being studied. In these traditional formulations of ethnographic work the notes, and any photographs, represented static representations. Changes over time in observations recorded in those notes or images might as well have represented changes in the interpretative lens of the researcher as much as they might represent change in the community. Even the ongoing interpretations that guided the fieldwork were usually the interpretations of only the researcher conducting the work. Newer technologies however have substantially altered the conduct of ethnographic field research and its analyses, and the incorporation of these tools into our research warrants a brief discussion of those new approaches.

Ethnographies that are conducted in the field over an extended period, particularly in remote locations, are often conducted by single individuals whose individual perceptual framing results in a very individualistic “view” of the field. In addition, anthropological work is often done in settings with which the researcher has come to as an outsider. In this type of situation field researchers are often concerned/cautioned against “going native” (or “returning to native”) as the study continues. However, few counterbalances exist which allow a researcher to monitor whether this is actually occurring.

Only 14 years ago, sociologists venturing into the field with a video camera were a novelty (Albrecht, 1985). However, use of this technology meant that it was easier to share ones field records and that analysis of those resources with others could help provide a more comprehensive interpretation of the data. In our field research a digital camera was used extensively to record pictorial “field notes.” These digital images (up to 70 a day) were used to keep records of field activities and acted as a memory cue to enhance the writing of field notes. In ethnographic work, digital imaging offers an advantage that film records do not—rapid availability of the images, re-usable storage media, compactness with high volume of images, and they are easily duplicable.

Observations of complex social activities are limited by the ability (and preconceptions) of the observer to see what is transpiring and record it in a meaningful fashion. Using a digital imaging camera and a video camera allowed the capture of social and analytical research structures that were developing and changing in an interactive environment. In addition, these technologies allowed a permanent record to be recorded for later observation and analysis. However, unlike ethnographic records relying solely on memory (head notes) or later-expanded field notes, repeated viewing of the digital images and videotapes allow more in-depth analysis and comparison with later episodes. From this work, observations could be re-focused and follow-up interviews conducted. Further, apart from the texts of any conversation, video recording allows records of clothing, vocal intonations, gestures (which are in its field-of-view), interactions between individuals and with artefacts, and so on and afforded an understanding of the process of field work unavailable from written notes alone.

Rapid electronic communication also meant that the field records could be shared with other researchers on a daily basis allowing field ethnographic research to be conducted collaboratively with other researchers. Each day the photographic images and field notes were sent to the other members of the research team back at the University of Victoria.

These members could read the field notes, look at the photographs, and even view video recordings (which had been couriered) allowing them to use their non-ecologists' perspectives to ask questions about the field practices being engaged in and provide guidance for the research being done. Thus, using more advanced technology encouraged the data collection process to be more comprehensive and encouraged analytical progressive subjectivity. This method of ongoing multiple analyses of the field ethnography research was quite successful at developing a comprehensive view of the field site and the practices engaged in there—further ethnographic research at the same site in the next season by another ethnographer expanded little on the data collected in the first field season.

Analysing Ethnographic Work

The analysis of ethnographic and anthropological research records is often poorly described in the literature, and even in most “methods” textbooks meant to be a guide for conducting and analysing research (see discussion by Barrett, 1996 especially at p. 208). The multiple research methods used in this project further compound the problems arising from this lack of guidance because individual studies reported in the literature rarely draw on the wide variety of approaches used here. To address this, the following discussion brings together three complementary analytic perspectives that together form the underpinnings of the analyses of the projects in this dissertation.

1. Interaction Analysis

The conduct of Interaction Analysis assumes that learning is a distributed, ongoing social process where the evidence that learning has occurred is found in the ways in which individuals collaborate in learning environments and recognise learning as having occurred (Garfinkel, 1967). It also is assumed that knowledge and skills (such as is found in “craft”) are fundamentally social in origin and situated in particular social and material contexts and which are evidenced in the interactions between members of a particular community who are engaged in the ‘everyday’ actions of their community. Practitioners of Interaction

Analysis (IA) assume that “verifiable observation provides the best foundation for analytic knowledge of the world” (Jordan & Henderson, 1995). Video and audio-taped records are essential for interaction analysis, as it is the interchanges between community members that provide the data corpus for the analysis.

When conducting IA, unlike other analytic approaches, categories are emergent in the analytic process as data sources are viewed and re-viewed. When a category is identified, or a tentative assertion made from the data corpus, the video and audio records are re-viewed to search for dis/confirming evidence of the validity of the categories and assertions arising from them (both need to be re-examined as the mere act of “constructing” a category can decontextualise and isolate the features being studied in such a way that subsequent assertions are unfounded). Such analysis can often provide guidance for, or indicate the necessity of, further fieldwork. Understanding learning, or cognition, or intents, is grounded in what is observable on the tape, not through inferences. For instance, students observed on a videotape sitting quietly for a lengthy period when looking at a word problem on a page would in other analyses be referred to as being “stuck” in solving the problem. However, with the lack of any verbal exchange or actions by the students, an Interaction Analysis would be unlikely to result in that interpretation. Only with evidence ‘in-the-air’ where students are indicating to others that this was the case, or where several different solutions were posed by the students to address the problem with none meeting what they considered was an acceptable solution, might an interpretation of “stuck” be considered valid. Ungrounded speculation about what an individual may or may not be thinking, or what they are motivated by, or what they intend, is discouraged when conducting an interaction analysis—only by referring to evidence on the videotape can they

be discussed. Thus, Interaction Analysis tends to be an inductive process generating assertions from general patterns observed in many sets of empirical observations.¹

2. Credibility and Validity

Collaborative viewing such as that conducted in Interaction Analysis is a powerful approach to neutralising pre-conceived notions of the interpreters and discourages any tendency to “see” what one wants or expects to see. This is particularly true when those conducting the analysis have experiences and interpretative frameworks that are dissimilar. Whether this analysis is conducted by groups of interpreters, or by researchers alone and then in groups, data and subsequent analysis which draws on multiple interpretative perspectives is said to have greater “ecological validity” (Jordan & Henderson, 1995) being more grounded in the ‘everyday’ practices of the community being studied than is that generated in artificial circumstances.

The concept of “credibility” is used in ethnographic interpretative research as a parallel to the positivistic criteria of internal validity (i.e., isomorphism between findings and an objective reality). In qualitative research “credibility” is the “isomorphism between constructed realities of respondents and the reconstructions attributed to them” (Guba & Lincoln, 1989) or, in other words, an assurance that there is a match between the constructed realities of the participants and those attributed to them by the analytic process. There are a number of ways in which credibility is established in qualitative research (ibid.), and each will be discussed in the context of the research work engaged in for this dissertation.

- a) Prolonged engagement - misinformation and misinterpretations of research settings are best avoided by engaging in extended work with the community in which one is doing research. In this case, the research was

¹ The section on Interaction Analysis drew from the comprehensive discussion of this analytic approach by Jordan and Henderson (1995).

conducted over three years with ecologists in a variety of settings. In part, this prolonged engagement is recommended so that a strong “rapport” and level of trust can be generated with the participants which best allows the uncovering of constructions and understanding the culture. In the work with ecologists a rapid establishing of rapport was possible also because of my past history as a field ecologist and therefore the research agenda was analytically productive almost from the beginning.

b) Persistent observation - in specific settings persistent observation enables the recognition of situation-specific relevant characteristics and elements that contribute to the interactions in that setting. The research in this thesis involved engaging as a participant observer/apprentice in field research with ecologists over four weeks, over two dozen videotaped interviews in which interpretations of inscriptions were provided, videotape records of all of the lectures and seminars of a second year university ecology class, attendance at over one dozen symposia and conferences, and extended interactions socially and in interview settings with ecologists as they discussed their research work. Thus, “persistent observation” was utilised in each setting.

c) Peer debriefing - Engaging with a disinterested peer in detailed discussions of findings, tentative analyses, and conclusions was an ongoing part of the analysis of this work. This took place in two ways. First, most papers presented in this thesis have been presented at conferences and subjected to critique by peers in that setting—either as part of the presentation or at some other time at the conference. Secondly, the research group I work with discussed this research in several instances. The mixed academic backgrounds of the group members (e.g., English as a second language education, pedagogical content knowledge, computers in

education, interactions with/in environmental groups) contributed to the analysis as they acted as an analytical sounding board reviewing both beginning and completed analyses. The distribution of field notes and digital images during the ethnographic work also contributed to peer debriefing and therefore contributed to the credibility of that research.

d) Negative case analysis - by examining negative cases and comparing them against the complete data corpus, a researcher can establish that all rival hypotheses have been examined so that the one which is argued for is the appropriate one. In the studies, which constitute this thesis, the peer debriefing and member checks (below) provided ample opportunity for negative case analysis. In some papers negative case analysis was explicitly conducted to foreground particular issues of concern.

e) Progressive subjectivity - This is the process of monitoring the interpretations being constructed by the field researcher. This can occur in numerous ways. For instance, in some cases I recorded extensive reflective notes on my own experiences and what I might expect in an analysis before and during engaging in the analytic process. These were used by other members in my interpretative group to check the interpretations I was developing to ensure I was not overly privileging my previous constructions. During the ethnographic research in the field with ecologists, the exchange of ethnographic field notes and the analyses I was constructing with my research group contributed to the process of progressive subjectivity.

f) Member checks - This is the checking of interpretations and instructions with members of the group being studied allowing the researcher to establish that the constructions being made have credibility with the

community members. In addition, it allows members to provide additional information and a chance to correct errors in fact or interpretation. Member checking was used in numerous aspects of this study, including roles played by conferences and social gatherings attended by ecologists, and interpretations of graph analysis. In addition, having the same concept addressed in different settings by different members at different times using different methods (e.g., interviews, observations, informal questioning) provides a form of qualitative ‘triangulation’ constructing a more comprehensive data set from which new information by new informants provides member-checking of ongoing analyses.

3. Hermeneutic Phenomenology

The research found in this dissertation is frequently an attempt to describe and interpret the lived experience of the participants in the study—to provide a derivation of the meanings and understandings they construe in their everyday world. Attempting to understand and explain the structures of the in-the-world experiences of the members of the community being examined does not, however, occur in a theoretical or experiential vacuum. An interpreter, or group of interpreters, attempts to recover the meanings in the ‘texts’ (a term which describes both lived experiences, symbols, and written artefacts) by making sense of them in terms of their own experiences. To do so explicitly, by viewing ones own experiences along a *hermeneutic arc* (Ricœur, 1991) which integrates (theoretically rooted) explanations and understandings of lived experience and using those insights to make sense of the data being analysed, is to be engaged in the process of hermeneutic phenomenology. In these, phenomenological readings engage lived experience and understanding, while hermeneutic readings engaged detachment and explanation. By engaging in a dialectic between such readings—through reflecting on my own apprenticeship experiences engaged in as part of this research and prior lived-experience as

an ecologist—I was able to develop greater understanding of the meanings of experiences to the ecologists by integrating my own prior understandings and experiences with those I observed them experiencing. Reflection on my own experiences as an ecologist was used to provide different “readings” of the data—for the same datum (for instance, a piece of transcript text), several different analytic notes were produced by examining that ‘text’ from the perspective of several different lived experiences. For a single datum (or case, etc.) therefore, different interpretations of its meaning could be generated which peers, members of the study group, or disinterested readers, could then critique. By using these critiques, combined with re-reviewing the data corpus, assertions stating general claims were developed which would then be offered for further critique.

In another study from the same data corpus used for the papers in this dissertation a different analytic approach, also rooted in hermeneutic phenomenology, was employed. In this study (Roth & Bowen, 1999) I generated extensive recollections of my experiences learning to use a particular form of inscription when I was conducting ecology research, while my co-author conducted a hermeneutic and structural analysis of the ‘texts’ obtained from our research participants. These alternate, distinctly different, readings were then used reflexively to move beyond a ‘surface interpretation’ of the meaning of the inscriptions to the ecology students and to instead generate a ‘depth interpretation’ (Ricoeur, 1991).

Summary

Analysis of any specific data set/case in this dissertation did not necessarily employ all of these methods or perspectives, but usually drew on several of these interpretative and theoretical frameworks. As is probably now clear, these different perspectives are not unrelated to each other and therefore it would be difficult, for instance, to claim that researchers were conducting an Interaction Analysis but one which was not related to hermeneutic phenomenology—it is not possible to escape ones own lived-experiences. These perspectives are also often complementary. For instance, engaging in apprenticeship

as an ethnographic field research method provides a deeper analytic approach when hermeneutic phenomenological interpretations are constructed providing for a triangulation of interpreted meanings. In addition, using that research method enhances the opportunity for member checking and thus contributes to analytic credibility.

Chapter 2:

Outline of Papers in Dissertation

This dissertation is comprised of a series of papers which examine the ways in which individuals are enculturated into the practices of ecology and, more generally, science research. From this, implications for teacher education and student learning of science are drawn. The research from which these papers originate accomplishes this by examining and contrasting the practices in which students and professional researchers engage when they participate in ‘everyday’ science practices such as designing and conducting research, interpreting data, and making knowledge claims. In doing this everyday work students and professional researchers draw on numerous experiential and textual resources to accomplish their goals and become enculturated into a world-view which takes a specific stance towards knowledge and knowing. The papers in this dissertation address the enculturation into scientific practices and implications of this for science education along five main themes.

1. Interpretation of Inscriptions

Use of inscriptions is a central practice of science underlying both research design and the resultant knowledge claims. Current science education reform documents call for the teaching of “authentic” scientific practices, thus the central role inscriptions play in science suggests that teaching students to use inscriptions as they are used in science would be of some importance. The first research paper, Chapter 3 (Covariation and graphical representations: Are (preservice) teachers adequately prepared to teach interpretation of data and graphs?²), examines the use of inscriptions by science program graduates, preservice teachers, and practicing researchers and compares and contrasts how they conduct their interpretations and arrive at knowledge claims. Evidence is provided that despite considerable preparation, and for many, despite B.Sc. degrees, preservice and practicing teachers do not enact the (“authentic”) practices that experienced researchers routinely do

² Prepared for submission to the journal “Cognition and Instruction.” Chapters in the dissertation differ stylistically with respect to both grammar and formatting because of the different audiences and journals for which each of the papers are intended.

when asked to interpret data or graphs. The detailed analyses suggest that traditional schooling emphasizes particular beliefs in the mathematical nature of the universe that make it difficult for many individuals to deal with data possessing the random variation found in measurements of natural phenomena.

Chapter 4 (Graph interpretation practices of science and education majors¹) more specifically addresses differences and similarities in inscription interpretation practices of preservice elementary teachers and science program graduates. This analysis was conducted to address the argument that for students to be effectively engaged in “authentic” inquiry practices elementary teachers need to have a better knowledge of science than they do—which various jurisdictions have decided can be accomplished by having pre-service education students take science courses instructed by science department faculty members. The paper examines the graphical analysis practices of preservice elementary teachers and science graduates on a number of graphing tasks and concludes that there were few differences between those two groups in their interpretations suggesting that having education students take the lecture-oriented science courses common to science programs would not necessarily improve their abilities at summarizing data or interpreting graphs.

2. An Analysis of Resources on which Students Draw for Interpreting Graphs

Chapters 5 and 6 suggest that students engage in different interpretative practices of inscriptions than do experienced researchers in part because of the resources on which they rely for interpreting graphs. Whereas experienced researchers have their research experience on which to draw for interpreting graphs with which they are unfamiliar, students have their experiences from lectures and the other various texts of science (including textbooks and journals). Chapter 5 (Lecturing graphing: What features of

¹ Prepared for submission to the “Journal of Science Teacher Education.”

lectures contribute to student difficulties in learning to interpret graphs?⁴) examines how graphs are used in lectures. Undergraduate science students spend a considerable amount of time in lectures and graphical representations play a major role in the presentation of subject matter in those lectures. This paper provides a microanalysis of graph use in lectures drawing on videotapes of the lectures and seminars in a thirteen week second-year university ecology course. This analysis focused on both the text and the gestural references made in the reading of a graph in an ecology lecture and concludes that the common ground existing amongst scientists which helps them reach an agreed-upon interpretation of a graph is absent from lectures placing constraints on the learning that students experience in lectures.

Chapter 6 (Why do students find it so difficult to interpret scientific inscriptions?⁵) examines the use of inscriptions in high school science textbooks, university ecology textbooks, and ecology journals. Four complementary analyses of their content are presented: (i) enumeration of the types of inscriptions in those resources, (ii) semiotic analyses of the content of representative inscriptions, (iii) interpretation by graduates of a science program of an inscription common to all three resources, and (iv) a comparison of an inscription found in textbooks and lectures with its original journal usage. The paper demonstrates that differences exist in frequency of different types of inscriptions which are unrelated to interpretive competencies of the students for whom they are intended. It also presents evidence that alterations made to inscriptions as they move from professional journals to textbooks actually confounds interpretation by students.

⁴ Published as Bowen, G.M., & Roth, W.-M. (1998). Lecturing Graphing: What features of lectures contribute to student difficulties in learning to interpret graphs? *Research in Science Education*, 28(1), 77-90.

⁵ Prepared for submission to the journal "Research in Science Education."

3. “World-view” Developed in Undergraduate Science Programs

Apart from what students learn in their classes about science concepts, concerns, and practices, they also implicitly learn how to look at the world—in other words they adopt a world-view consistent with the discipline they are entering. Issues of world-view are important if they place limitations on which issues are addressed by the discipline and what knowledge claims are made, especially if these limitations discourage participation in science or result in claims which are poorly founded. Chapters 7 and 8 examine how the structure of lectures and the research experiences of undergraduate science students results in their developing an anthropocentric, reductionist view of nature and ecology—which has implications for the conservation of organisms and inclusivity in education. Chapter 7 (Reductionism in biology lectures: Fables of the reconstruction^o) examines the covert manner in which students learn to adopt reductionist world-views in ecology, a discipline which is ostensibly concerned with developing a holistic world-view. This paper demonstrates how a particular factual way of presenting graphical representations affords ecology students to adopt reductionist world-views according to which understandings of ecological systems can be constructed from the knowledge of previously isolated variables and their measurements. Evidence from a second-year university ecology course is contrasted with data collected during ethnographic field work with ecologists, interviews with scientists, and autobiographical evidence that renders the depiction of scientific knowledge in lectures problematic.

Chapter 8 (Of Lizards, outdoors and indoors: Translating worlds in ecological fieldwork⁷) uses data collected during the ethnographic field work with ecologists to argue that how ecologists derive and investigate variables constructs a human-centered world and not an animal-centered one. Jakob von Uexküll, a prominent theoretical ecologist, noted in

^o Prepared for submission to the “International Journal of Science Education.”

⁷ Prepared for submission to the journal “Animals and Society.”

the beginning of the century that to understand the evolution of an organism biologists needed to understand the lifeworld (Umwelt) of the organism because organisms react and adapt to their lifeworlds rather than decontextualized, transcendental worlds. This paper argues that in contrast to von Uexküll's precepts, the ecologists who participated in the ethnography continuously attempted to construct a transcendental world which had decidedly human categories. These research practices run counter to an understanding of their organisms lifeworld, and therefore counter to a better understanding of the dynamics of the natural history of the organism and the environment within which it lives.

Taken together, these two papers suggest that the "authentic" science practices called for in science education reform documents need to be implemented with a critically reflective stance with respect to what knowledge it is that participating in this sort of activity actually develops.

4. Narratives in Ecology Research

Narratives play a central role in enculturation to a number of professions, yet we often do not structure educational settings to facilitate and promote the use of narratives to develop a community of practitioners. In addition, informal narrative exchanges are another under-researched area in sociological studies of scientists. These chapters examine the role that storytelling plays in constructing the community of ecologists, including the role they play in establishing membership and exchanging information about field research practices which are rarely discussed in the formal texts of the discipline. Chapter 9 (The roles of stories in communities of ecologists⁸) examines the various roles that narrative fill in the community of scientists who participate in ecology and field biology research.

Discussions of the components of social practice which constitute a domain often only focus on the socially-mediated influences directly affecting knowledge claims, but pay little attention to other informal interactions which are important to the 'community' but which

⁸ Prepared for submission to "The International Journal of Qualitative Studies in Education."

play less of a role in the development of knowledge claims. The paper relates the host of experiential stories drawn on by individuals who have engaged in field research practices to help develop their understanding of research situations and the social bonds of the community. The paper draws on ethnographic work with ecologists in their field, laboratory, classroom, and 'leisure' settings which are analyzed to examine the roles that stories play in the interactions of ecologists and the structuring of their community of practice and discusses implications for how we structure and conduct science classes in public schools.

Chapter 10 (The contributions of formal and informal settings to the formation of ecologists⁹) examines how stories fill a void present in the formal texts used to enculturate newcomers to field research practices in ecology. The formal texts of ecology (lectures, textbooks, journal articles, conference presentation) underdetermine the details of field research practices. In addition, this is also affected by the formal learning of ecology occurring in settings unlike where ecology research is actually conducted. Laboratory sciences, such as physics and chemistry, learn about the research practices of their discipline in settings similar to the environments in which such research is actually conducted. Ecology however is also learned in laboratory settings, or using structured field investigations, and this also results in little being learned about actual ecology research practices. Ethnographic work with ecologists highlights that narratives related in informal settings (such as over coffee, lunch, or in bars) are quite important for ecologists becoming enculturated into ecological field research practices and these narratives partly compensate for the lack of specifics about and practices engaging with field research in the formal texts of the discipline. The paper emphasizes that participating in these informal settings is a necessary practice for becoming a field ecologist.

⁹ Prepared for submission to "The Electronic Journal of Science Education."

5. Implications of Studies of Ecologists for Science Education

The ethnographic studies of ecologists have implications for how “authentic” science practices are viewed, for field ecology research deviates quite substantially from the physics-based model on which much of science education practice is based. Chapter 11 and 12 examine the implications of this work for how we view the conduct of science education. Chapter 11 (Biology as everyday social practice: Pedagogical implications¹⁰) addresses how science education would be viewed if the practice of science is viewed as a social practice. Traditionally, science has been primarily viewed as a body of knowledge which needed to be transferred to (or reconstructed in) the minds of students; this body of knowledge was thought to be complemented by scientific skills which students acquired by doing standard (recipe-like) laboratory exercises. Ethnographic studies of the everyday practices of biologists reveal a different image of what it means to know biology—it is constituted by complex lived and embodied experience which biologists appropriate by participating in the practices of/with more experienced peers. The paper argues that much of what makes a biologist is learned *in praxis* and *after* completing school and university. The paper presents case studies of knowing and learning biology from middle school to professional science and discusses implications of this for the design of learning environments in which individuals move along continuous trajectories from their initial school experiences with biology to full participation in biology as everyday practice (as scientists, environmental activities, informed citizens, etc.).

Chapter 12 (The practice of ecology research: Insights for science education¹¹) provides a detailed summary of insights for science education gleaned from the ethnographic studies of ecologists. This paper argues that many traditional claims about the nature of scientific research and knowledge are not consistent with how ecology research is actually

¹⁰ Prepared for submission to the journal “Science Education.”

¹¹ Prepared for submission to the “Journal of Research in Science Teaching.”

conducted. This has implications for the teaching of “authentic” science as it requires a re-conceptualization of how science environments for students would be constructed and perhaps offers an avenue for non-Western views of knowledge and nature to gain entry to the discussions of and about science in science classrooms.

The final chapter, Chapter 13 (Implications of studies of ecologists for teaching and teacher education) provides an overall summary which draws together the ethnographic field research, the interviews about field practices, observations of undergraduate ecology programs, and the research on interpretation of inscriptions to make recommendations for the education of student teachers and public school students.

Chapter 3:

Covariation and graphical representations: Are (preservice) teachers adequately prepared to teach interpretation of data and graphs?

Covariation and graphical representations: Are (preservice) teachers adequately prepared to teach interpretation of data and graphs?

Abstract

The interpretation of data and construction and interpretation of graphs are central practices in science which, according to recent reform documents, science and mathematics teachers are expected to foster in their classrooms. However, are (preservice) science teachers prepared to teach inquiry with the purpose of transforming and analyzing data, and interpreting graphical representations? That is, are preservice science teachers prepared to teach data analysis and graph interpretation practices which scientists use by default in their everyday work? The present study was designed to answer these and related questions. We investigated the responses of preservice elementary and secondary science teachers, practicing science teachers, and scientists to data and graph interpretation tasks. Our investigation shows that despite considerable preparation, and for many, despite B.Sc. degrees, preservice and practicing teachers do not enact the (“authentic”) practices that scientists routinely do when asked to interpret data or graphs. Detailed analyses of written or videotaped answers on the tasks are provided. We conclude that traditional schooling emphasizes particular beliefs in the mathematical nature of the universe that make it difficult for many individuals to deal with data possessing the random variation found in measurements of natural phenomena.

If scientists were looking at nature, at economies, at stars, at organs, they would not see anything. . . . Scientists start seeing something once they stop looking at nature and look exclusively at prints and flat inscriptions. . . all laboratory observers ha[ve] been struck by the extraordinary obsession of scientists with papers, prints, diagrams, archives, abstracts, and curves on paper. (Latour, 1990, p. 39)

Ethnographic research in scientific laboratories and scientific field work has shown that designing investigations, collecting data, transforming data, and interpreting the resulting representations are some of the quintessential scientific practices (Latour, 1993; Roth & Bowen, 1998). Recent reform documents have increasingly called for such “authentic” practices in mathematics and science education which would allow students to engage in these subjects in ways that correspond to everyday practices in these fields (AAAS, 1993; NCTM, 1989; NRC, 1994). For example, mathematics curricula in Grades 5-8 should enable students to (NCTM, 1989):

- describe and represent relationships with tables, graphs, and rules; (p. 98)
- analyze functional relationships to explain how a change in one quantity results in a change in another; (p. 98)
- systematically collect, organize, and describe data; (p. 105)
- estimate, make, and use measurements to describe and compare phenomena; (p. 116)
- construct, read, and interpret tables, charts, and graphs; (p. 105)
- make inferences and convincing arguments that are based on data analysis; (p. 105)
- evaluate arguments that are based on data analysis; (p. 105)

- represent situations and number patterns with tables, graphs, verbal rules, and equations and explore the interrelationships of these representations; (p. 102) and
- analyze tables and graphs to identify properties and relationships. (p. 102)

These competencies mirror the daily practices of scientists with their focus on data collection, analysis, and presentation and are thus easily integrated with science curriculum reform at the same grade levels. In fact, the integration of mathematics and science school activities may not only be interesting because children collect their own data, but may be essential for developing a thick layer of experiential knowledge that underlies much of scientists' understandings (Roth, 1996; Roth & Bowen, in press; Roth, Masciotra, & Bowen, 1998). Such integration of rich experiences with physical phenomena and subsequent transformation and analysis of the data appears to lead to robust mathematical *and* scientific understandings of phenomena (Greeno, 1988; Roth & McGinn, 1998).

To date, many science and mathematics teachers have not yet realized the potential that lies in situating mathematics in students' self-directed inquiries about natural environments as a way to implement these NCTM standards. Moreso, there is some evidence that science teachers may not enact competent data interpretation themselves (Roth, McGinn, & Bowen, 1998) making it difficult for them to scaffold students in these practices. The present study is therefore fundamentally concerned with the question, "Are (preservice) science teachers prepared to teach through open-ended inquiry?" Specifically, we were interested in answering questions such as "How do (preservice) science teachers analyze a given set of data previously collected and presented by Grade 8 students?," "How do (preservice) science teachers interpret a graph from published research?," and "How do preservice science teachers analyze and interpret data which they themselves collected and transformed?" Furthermore, we were interested in understanding the (preservice) teachers' performance relative to scientists analyzing the same data and interpreting the same graphs which were presented to them.

Inscriptions: A Social Practice Approach to Representations

Our theoretical approach for studying science in schools, university, and professional practice is informed by the emergence of anthropological, ethnomethodological, and sociological studies of scientists at work (Latour & Woolgar, 1986; Lynch, 1985; Traweek, 1988). All of these studies take a common perspective of science as a set of practices that are shared by members of specific communities—which is in contrast to more traditional work on science that saw in scientists a special breed of people who use special skills and procedures to cull facts from nature. Thus, these studies of scientists at work view knowledge not as something residing exclusively in the heads of community members but rather as something constituted, to a large extent, by the ways people (e.g., scientists) go about their daily business, how they justify what they do, the stories they tell, and so on.

Inscriptions are two dimensional representations of data that can then be transformed into other inscriptions; ultimately, they are included as tables or graphs in scientific publications. Inscriptions are therefore the result of scientists' work which converts research experiences into a form that is easily shown to others. Using inscriptions, natural scientists have converted information about trees, moving lizards, soil, and screaming rats into representations which they can then use to help form the rhetorical basis of their claims (Latour, 1993; Lynch, 1990; Roth & Bowen, 1998). Inscriptions are central to the practice of science because they can easily be cleaned, transformed, superposed and labeled such that they can be incorporated as an evidentiary base into scientists' conceptual arguments. As part of scientists' argument construction, physical phenomena are moved through series of inscriptions that may include, in increasing order of complexity, such re-representations as maps, lists, tables, totals, means, graphs, and equations. Through these transformative processes and the resulting inscriptions, scientists both construct and see phenomena; without inscriptions there would be few scientific phenomena. Thus, using data sets to

produce inscriptions which can be used in publications is a core scientific practice (Latour, 1987)—one that it would be expected that graduates from a science program would automatically use as part of structuring their arguments in a scientific investigation. This expectation is not unreasonable given that this degree of competency has been documented with younger students conducting independent inquiry projects; one of our own previous studies documented the extraordinary competencies of Grade 8 students in constructing and transforming inscriptions when they conduct their own field-based research (Roth, 1996).

The use of graphs, and other types of representations, is something that students of all ages have difficulty using appropriately (Leinhardt et al, 1990; Schnotz, 1993). In related studies we have detailed the difficulties which second year university science students had while interpreting graphical representations in seminar discussions (e.g., Bowen, Roth, & McGinn, in press). The foundations of the students' interpretive difficulties in seminar sessions were shown in a microanalysis of the text and gestures accompanying the presentation of graphs in the lectures for that course. This analysis suggested that the interpretive framework of the lecturer differed from that of the students and that this derived from different experiences at collecting and summarizing data and that the gestures over the graph were from one who "knew" the graph being unlike those which would be made by those who did not "know" the graph (Bowen & Roth, 1998a). Together, these differences lay at the root of the student difficulties observed in their seminar.

Covariation

Scatterplots, bestfit functions, and other graphs in Cartesian coordinates are ideal for representing the continuous covariation of two variables which would be difficult to express in words. Because of its typological character, language is well suited to expressing differences and categorical distinctions. On the other hand, graphs have a topological character well suited to expressing quantity, gradation, continuous change, continuous covariation, varying proportionality, and other complex topological relations of

relative nearness and connectedness (Lemke, 1998). Graphs are sign forms which can therefore be used within particular communities to represent the topological and dynamic character of relationships. An analysis of scientific research articles from 5 journals covering over 2,500 pages showed that graphs which display the relationship of two or three variables are *the* preferred method of representation in science (Roth, McGinn, & Bowen, 1997). Sociological analyses have shown that graphs are predominant because, in the practices of scientists, they have the greatest rhetorical power (Latour, 1987). Although tables could also be used to show how the concurrent associations of measures of one quantity vary to that of another, the relationship across the entire data set is only implicit in tables whereas graphs make the association immediately available in visual form (Bastide, 1990) allowing readers to note patterns in the data as well as discrepancies (e.g., outliers).

Research Design

Tasks

This study was designed to understand (preservice) teachers' graph interpretation practices relative to the representations and transformations which they are expected to teach according to the reform document guidelines. We investigated these practices in three conditions. First, participants were asked to interpret a set of raw data presented on a map of the research site (Lost Field Notebook); the data did not easily reveal a relationship given the scatter and one potential outlier. Second, we asked participants to interpret a graph originally published in the scientific literature and which later, with modifications, appeared in textbooks and in an ecology lecture (Plant Distributions). Third, we presented participants with a task where they had to design their own investigations, collect data, transform data, and interpret the transformed data (Investigations).

These three tasks represent three different levels of "authenticity" as they would be experienced by students in post-secondary science programs. The Lost Field Notebook

problem represents a “school-like” task such as students encounter in problems sets from university science seminars and lectures (Bowen & Roth, unpublished data). The Plant Distributions task asks students to provide an interpretation of a graph which is similar to those they would encounter when reading a journal article; a common task for senior-level science students conducted to support research activities on which students were reporting. Finally, the Investigations task reflects scientific practice in that it contains the components of most scientific research: framing a question, operationalizing variables, analyzing data, and making claims from that data. Together, these three tasks represent the main components of undergraduate science education which would deal with developing competency in conducting scientific research.

The three tasks also differ in terms of the translation processes required for making claims about the relationships between the relevant quantities (Janvier, 1987; Roth, Tobin, & Shaw, 1997). The Lost Field Notebook requires double transformation: first, the relationship between the measure has to be uncovered (e.g., using a graph, curve fitting procedure, statistical analysis, etc.) before the relationship can be translated into a verbal description of the situation that may have led to the particular data at hand. The Plant Distributions requires one translation, for the relationship is visually available. Finally, the Investigations task requires a complete cycle of activities from situation descriptions that identifies the variable categories, through measurement, representations, before another verbal description of the covariation can be related back to the situation. These translations are expressed in Figure 1. Unlike Janvier (1987), however, we pursue the translations not as psychological processes, but as social practices that are embedded in other social practices, and that are appropriated by individuals as they increasingly participate in communities where these practices are what everybody else is doing (Roth, 1996; Roth & McGinn, 1998).

[Insert Figure 1 about here]

Lost Field Notebook

The Lost Field Notebook task originated in an earlier study (Roth & Bowen, 1995) where it was designed to test a research hypothesis about practices of data interpretation among Grade 8 students engaged in a 10-week field study of different ecozones. The representation of the data in the map is a facsimile from the notebook of one Grade 8 student involved in the study. We wrote a stem that situated the data in the same context in which the children worked at the time in order to assess their data transformation practices using a problem that was as ecologically valid as possible. For the purposes of the current study, we selected one of the forms containing 8 plots and therefore 8 pairs of numbers (Figure 2.a). The graphical representation of the data in a Cartesian graph shows the ambiguity of the relationship (Figure 2.b). We chose this particular problem for at least three reasons. First, its apparent correspondence to a plausible experience seemed strong (even our scientists never questioned the authenticity of the data). Second, the problem is equivocal even for individuals with much more experience in research (e.g., graduate students). As Figure 2.b shows, the correlation changes from a nonsignificant to a significant relationship when Point C is considered an outlier and dropped from the analysis. This change in significance promised cognitive conflict (and discussions between pairs of participants discussing the task) and, for us, an opportunity to study sense-making over and about those representations that participants constructed to support their arguments. Third, the problem was interesting because it is quite similar (in the scatter of the data) to scientific data sets as they emerge from ecological field work (Roth & Bowen, 1998) and in ecology research journals (Roth, McGinn, & Bowen, 1997).

[Insert Figure 2 about here]

Plant Distributions

The Lost Field Notebook problem required some form of transformation before any conclusions about the natural environment could be made. Problems in the interpretation potentially arise even when the covariation is already represented in graphical form. We therefore chose a second task with a similar underlying variation (i.e., plant density as a function of a physical variable). To ascertain closeness to scientific practice, we chose a graph from the ecological literature (Eickmeier, 1978), but modified it in ways similar to those used as lecture material in a university lecture course (i.e., clarified captions, reduction of variation in major trend-line patterns; Bowen & Roth, 1998a). The original research by Eickmeier was conducted to show that, consistent with a theoretical model about adaptation and niche exploitation, different photosynthetic mechanisms allowed plants to best thrive in different climatic conditions. C3 (Figure 3) is the simplest, but most water consuming mechanism based on a one-cycle chemical process. The C4 mechanism conserves water by adding another cycle of chemical processes. The CAM mechanism is similar to C4, but the second cycle occurs in separate cells, so that gas exchange associated with the first process can occur at night; this process is separated from the second one which occurs during the day thereby minimizing water loss through the pores.

[Insert Figure 3 about here]

Modification of the inscription occurred in two ways. First, several local minima in the functions were eliminated to make for more continuous curves. Second, the temperature and moisture gradients were plotted above the graphical display. We used a caption similar to those found in the scientific literature, and added a reference to the literature so that respondents could see that the graph had come from the scientific literature. In this way, the graph was not unlike those several hundred identified and analyzed during a previous study of five ecology journals (Roth, McGinn, & Bowen, 1997). Participants were asked by us

to describe how they interpreted the graph and to provide us with their understandings of what it might represent.

“Authentic” Investigations

Responding to tasks provided in the form of the previous two problems, though considerable context had been provided, can be criticized as too school-like in that the data and representations are preframed (Lave, 1992; Roth, 1996). We therefore asked one subset of our participants to design and conduct an investigation in which correlations between biotic and abiotic features of the environment were to be studied. They were told that the investigation should be framed in the form of two focus questions and include relationships based on some form of quantitatively measured variables. The students were to report their results using a scaffolding device, the Epistemological Vee (Novak & Gowin, 1984), to which they had been introduced previously. This device explicitly prompts users to state research questions, provide a brief description of their research method, report data, transform the data, and state claims based on the data. Because users are required to state their prior knowledge also, they can, after the fact, assess their learning in the process of the inquiry. We asked two of our scientist participants to comment on selected case analyses of reports written on these investigations.

Research Participants

Preservice Elementary Science Teachers

These participants were enrolled in a Western Canadian university in their last year of a five-year elementary education program and had chosen science and mathematics as their subject matter specialty. They had taken a number of related courses, beyond the minimum required, in order to receive their specialist degree. The 10 preservice teachers (7 female, 3 male) constituted the entire class of an advanced science curriculum course, the only one offered during that school year. Nine of these preservice teachers had above-average GPAs

in the elementary education program. (All pseudonyms start with the letter E to indicate students in the elementary education program.)

Preservice Secondary Science Teachers

These participants were enrolled in a secondary science teacher preparation program in a different university in Western Canada which accepts applicants only after they have previously completed a bachelors degree. All 25 students (10 male, 15 female) had previously completed undergraduate degrees with a major either in science (22 students), mathematics (2 students), or in the arts (1 student). Four students had obtained post-graduate degrees in: veterinary medicine, mechanical engineering, chemistry, and law; they also had work experience in their respective domains. (All pseudonyms start with the letter T for teacher.)

Practicing Science Instructors

Four science teachers (2 high school teachers, 2 university instructors) all with a B.Sc. degrees (ecology, 2 biochemistry, physics) participated in the study. Three had participated in research as assistants, but none had conducted independent research for the purposes of publishing the results of their studies. Their experience ranged from first year to more than 20 years of teaching. (All pseudonyms start with the letter I for instructor.)

Practicing Scientists

Over the past two years, we have asked 20 practicing scientists to interpret various scientific representations, including different sets of data and graphs. All sessions were videotaped and transcribed. For the present purposes, we included 15 individuals, 10 individuals who responded to the Lost Field Notebook problem and 10 individuals who responded to the Plant Distribution Graph (with 5 individuals doing both). The individuals had a minimum of five years of research experience and at least a M.Sc. degree. The domains of their work differed widely including ecology, entomology, marine biology,

physics, chemistry, and forest engineering. (All pseudonyms start with the letter S for scientist.)

Task Distribution

The participants contributed to different extents, formats, and social settings in our data base. The distribution of think aloud, group sessions, and written task environments across the different participant groups is shown in Table 1.

[Insert Table 1 about here]

Data Sources and Interpretations

The present study was developed from a data corpus that includes (a) videotapes of individuals (scientists, science teachers) and groups (preservice elementary science teachers) solving the Lost Field Notebook problem and interpreting the Plant Distribution Graph; and (b) written solutions by individuals (Lost Field Notebook) and groups (Authentic Investigation) from the preservice secondary teacher population.

Our interpretations inscribe themselves within the larger context of studies on the interpretation of scientific representations from middle school to professional practice; our studies draw on semiotics of scientific texts (Bastide, 1990; Eco, 1984) and interaction analysis (Jordan & Henderson, 1995) as the major methodological frames. We analyzed the data individually (in part to later assess the robustness of our categorizations) and, later, in collaborative sessions. In daily meetings, we generated assertions and tested them individually and collectively in the remainder of the data base. The transcripts and videotapes were taken as occasions for construing the public work done of providing a solution; in the cases where we had videotapes of pairs, it was expected that, if there was any trouble during the interpretation, the participants would try to remedy the breakdown by talking to each other. Our transcripts were therefore protocols of individuals' and

groups' efforts in making solutions to the tasks as they understood them accountable to the researchers or to each other.

Findings I: Interpreting Raw Data

Our overarching question was whether (preservice) teachers enacted the scientific and mathematical practices described by reform documents (NCTM, 1989) in appropriate situations. Specifically, our first question asked "How do (preservice) science teachers analyze a given set of data previously collected and presented by Grade 8 students?" To contextualize the answers by (preservice) teachers, we present scientists' responses to the same task.

Scientists' Readings

If you possibly plotted out the graph, then did a linear regression on it, you might see an R^2 value that actually makes sense.

In the course of our inquiry, we asked ten active researchers working either at a university or in the public sector, and all of whom had M.Sc. or Ph.D. degrees, to examine and provide an interpretation for the Lost Field Notebook problem. Without exception, these participants ended up plotting the data, proposed regression analysis to test goodness of fit, discussed an outlying data point, and suggested the collection of additional data to increase the power of the statistical analysis. The scientists were unanimous that, to make a convincing claim, they had to plot the data and provide statistical indicators about the strength of the relationship. Providing a data plot and the statistical information would be their way of supporting the claims. Without exception, all practicing scientists indicated that there appeared to be a relationship which should be substantiated by statistics and collection of further corroborating data.

Scanning the Map

Three scientists, after reading the story plot, immediately, without scanning the data and without hesitation, suggested plotting the data and subsequent statistical analysis. The others engaged in a more lengthy process of scanning the map, making tentative claims, plotting the data, and then conducting their analysis followed by statement of claims. The difficulty in our analysis lay in assessing what occurred during the first few seconds of seeing the map, because few participants verbalized what they focused on. But a few did. In the first reading, things become salient, that is, the reading establishes a domain ontology. Some scientists noticed the irregular plots, but this aspect did not enter their interpretation at all.

Scanning for extreme cases and data points at “opposite ends” of the data range was a common practice. Thus, some scientists began by seeking those areas with the lowest light intensity or bramble density, and then moved to identify those with the highest values on the same variables.

I’m looking at, say just these three which were the lower ones in this corner [top right], 750 to 500, and then looking at these three [D] [H] [E], 12, 15 are of the two highest levels and these [C] [F] are the two lowest levels. [Stu]

As they scanned the map, scientists noted the potentially discrepant data. But rather than using these data for drawing conclusions, this noting was simply part of establishing the domain ontology, which also included other aspects such as the irregular size and boundary of plots, the absence of “edge effects,” the differences in the size of the plots, or the identification of those plots in which the extreme cases on either variable were located.

Tentative Claims

The first, tentative claims after scanning the map were not consistent. In equal numbers, the scientists initially suggested that there was and was not a pattern, that is, a

relationship between the two variables light intensity and bramble density. A typical statements was:

So, at first glance, it would seem that there is not much of a pattern or a relationship between foot-candles and percent coverage by brambles. [Steve]

At this point, rather than using individual data points for or against their claims, scientists then proposed to plot the data. Some immediately proposed subsequent statistical analysis to find correlations, and then outlier analysis.

If you possibly plotted it out, plotted out the graph, then did a linear regression on it, you might see an R^2 value that actually makes sense, that's why I would plot this data if I was, wanted to see a pattern. So just looking at it like this, doing a linear regression plotting percent cover versus light intensity, see if there is a line there, then calculate R^2 and if we did that we probably would see some kind of a pattern with increasing cover and increasing density, so, more light equals higher density of brambles. [Stu]

Data Plot and Analysis

Scientists plotted the data, and with one exception, used light intensity on the abscissa and bramble density on the ordinate. After the data were plotted (as in Figure 2.b), scientists were unanimous about the (weak) relationship between the two variables. They then engaged in an analysis of discrepant data. For example, after having suggested that there "vaguely was one" relationship, Sally assessed the effects of possible outliers.

Take that out [C], take that [D] out. Just to remove outliers, so if you remove an outlier to see if there is, if it's a single point that sort of driving the whole relationship. So if you take that [C] one out, it's not bad. But like this one [D] up here, if you take that out, I'd say . . . you're grasping at a relationship. And if you take that [H] one out, it doesn't change it too much. I would go to this point [F] is

that 500, 0, no, this one [C] is 500 foot candles, 30%, see that one [C] looks a bit suspicious because there is so much variation between those two. [Sally]

After this analysis, Sally concluded that there was a “positive relationship between foot-candles, or the amount of light they get and how many brambles there are.”

There was only one scientist who proposed a curvilinear relationship. In contrast with the other scientists, he plotted light intensity over bramble density which provided him with a different perspective. He drew a best fit curve which was parabolic and then explained (Figure 4):

The only pattern I might see is that pattern GESTURES[parabola], somewhat like that, but not a super strong one. That suggests that there is some intermediate light level at which bramble coverage is greater. So I might claim that brambles have a optimum light level intensity in which they grow and reproduce optimally at, and the higher or lower light levels, their growth and reproduction is decreased. [Steve]

[Insert Figure 4]

In dealing with the outliers, scientists suggested the collection of additional data, checking whether there were copying errors from a notebook, or seeing if there’s “something weird about that region that results in either high ones, that resulted in a really high percentage with such a low.” One scientist proposed running consecutive regression analyses:

There are statistical tests that can be used, curve fitting. The simplest one is straight line relationship, the R^2 statistics tells you how well the best fit straight line through a series of data points fits and now you can run that leaving certain data points out or leaving all the points out sequentially and seeing which one gives you the best R^2 or the best fit. [Stu]

Another scientist proposed the use of statistical indicators such as Mahalanobis and Cook's distances which can assist in deciding whether an outlier significantly affects the relationship, and whether or not a data point could be dropped. (Many statistical packages have this option.)

Other Factors

Our prior research suggested that many non-scientists seek to explain the variation in both variables by drawing on explanatory resources outside of the written problem itself. That is, drawing on personal experience, they invoked other variables that might explain the particular data set in front of them. This was corroborated in the present study among the non-scientist individuals. On the other hand, scientists were only marginally concerned with other possible factors. Usually these concerns became evident before they actually plotted the data. For example, one scientist, after the first scan of the map, suggested that two plots [C,F] had particularly low light intensities which he thought were possibly due to shading by other trees. Another individual suggested that a water source at the western edge might be a mediating factor.

Suggestions for Improving Elizabeth's Study

Scientists were almost unanimous about the fact that the number of data points should be increased, though at least one suggested that she herself had conducted and reported research based on 12 data points. Another common suggestion was to try and work with plots of equal size, though the scientists also realized that density was a relative measure and light intensity had been averaged across the plots. One scientist also suggested that it might be better to work with the absolute numbers of brambles in areas of normed size, but was uncertain whether this would improve the quality of the measure.

You could actually calculate the absolute amount of brambles, which might be a better measure. I mean, ideally it might be better trying to layout defined, like areas of equal size. [Sally]

Think Aloud Protocols by Instructors

There has to be another variable involved in what's happening here because a direct correlation between light intensity and percent density of the bramble doesn't seem to hold true.

Four instructors (2 university, 2 high school) with B.Sc. degrees were asked to think aloud as they completed the Lost Field Notebook problem. All four, without exception, inspected the data and, without any transformation, claimed that there was no relationship between light intensity and bramble density.

I mean it seems, you know, the higher [D], the higher light higher coverage, but then when you look at like between 200 [D] and [E], between 1200 [D] and 1500 [E] it looks like that but then when you look at this one [H], well, that's not very high, so why not? like [D] [E] it doesn't [H]. [Ina]

Tentative Hypothesis and Testing

Three of the four instructors engaged in cycles of explicitly verbalizing at least one tentative hypothesis, and then rejecting this hypothesis based on an analysis of individual data points. "High percent, lots of light [D], low percent, lower light [G] higher light and higher percent [B]" (Ike) "it seems, you know, the higher [D], the higher light higher coverage" (Ina).

One could argue that all brambles need light but then that's defeated by the fact that we've got light 500 foot candles here [F] and no brambles at all. One could argue that brambles need more than 500 foot candles to grow but that's [C] defeated by

the fact that you've got 30% incidence with the self same 500 foot candles that over here [F] was not growing anything. [Ira]

[Insert Table 2 about here]

Three of the four used pairwise comparisons of data points (Table 2). In a few instances, three [D,C,E] and five areas [A,B,F,G,H] were clustered to obtain geographical patterns. In these instances of comparisons, two types of comparisons were used, within variable comparisons and between variable comparisons starting either with the light intensity or the density comparison. Usually, this pattern was used to show exceptionality, that is, for an equal or similar value in one variable there was a drastic difference in the measures of the other variables such as in the comparison of [C] and [F], 500:500::30:0.

One person (Ira) used the trend within a pairwise comparison as a counter argument against an overall trend. Thus, whereas the light intensity increases going from Plot D to Plot E (1200:1500), the opposite trend is observable for the coverage (40:30). This was interpreted as indicating a negative relationship held against an overall positive correlation.

Two individuals [Ira, Ian] crossed the arguments. For example, then comparing the areas [C] and [D], the argument ran 40:1200::1250:15 ("40 is what you were seeing at here [D], 1200, while this [H: 1000] is down to 15% here [H: 15]").

Two individuals [Ian, Ina] considered three data points as they searched for consistency among data points. Ian compared the data set [H,A,D] in both a between [1250:15::1000:10::1200:40] and within [1250:1000:1200::15:10:40] condition concluding in both cases that [D] was a discrepant point with respect to coverage. His other three-point comparison consisted of the set [DCE] for which he used a within comparison [40:30:30::1200:500:1500] to conclude that [C] showed a discrepancy with respect to light intensity. Ina tested the hypothesis "higher light, higher coverage" and then proposed the set [DEH] to reject it [1200:1500:1250::40:30:15] because the coverage in [H] was low.

Although each individual made a number of comparisons, when they were asked what they claimed and how they supported it, they generally used one example to contradict the relationship between light intensity and bramble density.

Pattern Map: “There is Something through this Area”

As they abandoned the search for relationship between the two variables, individuals proposed geographical pattern in which the western edge [D,C] and Plot [E] with high bramble densities were opposed to the low densities in the remaining areas.

I have a hard time saying the more light, the more brambles ‘cause that’s not entirely true. It’s almost as if there is something down through this segment CIRCLES [G,B,F,H,A] of the land here that’s just decreasing the amount of brambles, and this [E], and this [D], or this [E] is an erratic, I’d be curious if something happened on this side POINTS[right map boundary] [Ian]

One person suggested that Plot E may be an outlier to the general pattern of the east-west (right-left) geographical pattern of bramble density. Thus, whereas we initially assumed pattern maps to be an independent strategy (e.g., Roth, 1996), the present data suggest that participants only engaged in this practice after exhausting other options and after suggesting that a covariation does not exist.

Other Factors

All four proposed that any weak relationship was spurious and that factors other than light determined the density of brambles.

But the thing that she is actually measuring is the differences in soil quality, for example, or differences in water in the different areas. [Ina]

Whereas the physics instructor (Ian) did not get into any specific alternative, the others proposed a variety of factors including water, soil quality, soil characteristics (such as a rocky outcrop underneath Plot F), and seed distribution. One person (Ina) also suggested

that more data should be collected in order to make more founded claims and check whether the distribution of the plants within each plot is fairly homogenous or whether the plants come in clusters. Another individual (Ira) thought that, because of the small size of the area covered by the map, there might possibly be considerable experimental error in the determination of the bramble density.

Preservice Teachers' Readings: Prior Work

A pilot study ($N = 17$) and an initial survey ($N = 32$) (Roth, McGinn, & Bowen, 1998) based on written tests showed that only a small fraction of secondary preservice teachers (5 of 49), despite their prior B.Sc. and M.Sc. degrees (most of them in biology), used graphical and/or statistical analyses when responding to the Lost Field Notebook problem. Statistical comparisons revealed that there was a significantly higher proportion of Grade 8 students (who solved the problem in pairs) who used graphical and statistical analysis methods than secondary preservice teachers. Having classified responses into more abstract representations (graph, averages), less abstract representations (ordered table, pattern map, list), and no transformation (language-based), we detected a significant effect ($\chi^2(2) = 6.80, p < .05$). There was a lower incidence of more abstract representations among preservice teachers than among pairs of Grade 8 students. Furthermore, there was a relationship between the type of analysis and the type of claim respondents made. A logit analysis—with type of claim (correlation, no correlation) as dependent variable and type of representation (more abstract, less abstract, none) as independent variable—showed that an equi-distribution model had to be rejected, $\chi^2(3) = 16.42, p < .001$. Analyses by respondents based on statistical and graphical methods generally suggested a positive correlation between light intensity and bramble coverage, whereas analyses based on other methods generally ended in claims that there existed no relationship between the two variables.

In the present study, we had two objectives. First, we wanted to collect verbal protocols of individuals and pairs to better understand the processes by means of which (preservice) teachers arrive at the particular claims and how they select the method for supporting their arguments. Second, we assumed that preservice teachers in the previous study, despite their scientific training (and B.Sc. degrees), did not use graphical (or statistical) analysis because they had not recently engaged in activities in which drawing graphs and doing statistics is “what is normally done” and “What everyone else does.” We expected that the frequency of graph use would increase if the participants were primed. We therefore repeated our earlier studies with preservice secondary science teachers but in a new condition: We primed participants immediately prior to the Lost Field Notebook with an activity that required them to answer the question, “How does the height from which you drop a ball affect the bounce?” by collecting and recording data, transforming the data into a Cartesian graph, and drawing conclusions from this graph. Specifically, they were asked to construct a scatter plot and to base their interpretation on this plot. Participants recorded the entire activity using the “epistemological vee” (Novak & Gowin, 1984) as a scaffold which provided prompts for them to engage in particular steps, from question to design, data collection, data transformation, analysis, and statement of claims. However, we also expected (based on our 20 years of combined experience teaching science in middle and high schools) that, because they had little prior experience in data analysis, at least some participants would reject a relationship between the variables in the LFN problem because the data did not fall on a (straight or curvi-linear) best fit graph.

Individual Written Answers after Priming (Preservice Secondary Teachers)

The missing field notebook exercise was very difficult for me.

As in the previous study, and despite their science degrees and the priming, preservice secondary science teachers found the Lost Field Notebook activity difficult. One of the individuals who produced a data plot with a line of best fit suggested:

It is very clear to me that I was taught science as a collection of facts, not as an exploration. This exercise was very difficult for me. I can see its usefulness already. I think it is important to have this kind of “thinker” exercises included in the curriculum. [Todd]

Another person suggested, “What was that Lost Field Notebook exercise all about? I couldn’t make any sense of it. Now I really feel like a non-science type” [Tandy].

Drawing on Latour (1987) and our own prior work, in this study we categorized answers along a continuum {no transformation (verbal)—>Ordered Table—> Ratios, Data Plots, Data Plots + Bestfit}. Table 3 shows that, possibly as a result of the priming activity, a large fraction of participants drew graphs (44%) compared to our previous studies. However, there were only 7 individuals (26%) who used lines of best-fit (two with outlier analysis) in the way we observed the scientists use them. Furthermore, we found an almost clean break between the claims made by those participants who plotted data accompanied by best-fit and outlier analysis and all other solutions, including those that had only plotted the data: Those who claimed that there was a relationship in the complete set of the data had all used in their analysis a line of best-fit. Generally, there was a much larger number of enumerations and discussion of other possible factors that determined bramble density among those responses that did not use plots and lines of best-fit and therefore claimed that there was no relationship between the two variables. There were only 7 cases where quantitative comparisons between two data points were made, 6 of which were related to a comparison of Plots C and F.

[Insert Table 3 about here]

Data Plots, Bestfit Lines, and Outliers

Figure 5 shows one of the solutions in which data are plotted, a line of best fit drawn, and the analysis of one data point as an outlier. Four of the pre-service secondary teachers

also constructed a table which appeared prior to the graph on the answer sheet; two individuals initially suggested on the basis of the table that there was no relationship, one person (Ph.D. in mechanical engineering) disregarded the table in favor of the graph, and the fourth person had constructed a table in which the light intensities for same-value coverages were already averaged permitting the conclusion of a positive correlation.

[Insert Figure 5 about here]

One individual, before plotting the data, prepared a data table ordered according to the percent coverage but for each value, averaged the associated light measurements. She then plotted the reduced number of data points (5), produced a line of best fit and concluded that there was a positive relationship between the “% brambles and # fc.”

The one person who concluded that there was no relationship despite having drawn a line of best-fit, initially began with an ordered table. She argued that the “variance from the line of best fit suggests an inconclusive relationship. . . supported by the fact that both 0% and 30% have a value of 500 foot candles” (Tora). In this, her argument was similar to those by the individuals using data plots only without accompanying lines of best-fit and outlier analysis.

Data Plots Only

When participants used data plots but without accompanying lines of best fit, the claim in all cases was that a relationship did not exist (Table 3). Of the five claims, three were supported by citing discrepant data points, the remaining two simply by referring to the scatter of the data that did not permit the attribution of a clear relationship.

It would appear that an increase in foot-candles in and of itself does not consistently result in an increase in brambles. Rather, it would appear that the amount of outside (presumably unobstructed access to light) area is indicative of the increased brambles. For example, if you compare the outside unobstructed light of the one

with the smallest amount [F], the density is 0% versus the one that is in the triangular area [C] which has a larger unobstructed area having a density of 30%.

[Tabby]

One student [Tanya] split the entire field in an upper and a lower area and produced plots for each set of four data points separately. For the plot containing the data of the upper four areas {D, G, B, F}, she claimed the existence of a relationship whereas in the case of the remaining data, she claimed that there was no relationship. An analysis of the two graphs shows that in the first instance (Figure 6.a), the data can be thought of lying on a curve, whereas this is not the case for the second plot (Figure 6.b). This analysis further supports our claims that participants who have not engaged in science as daily routine activity tend to assume that relationships between variables have to be ideal in the sense that data points fall on (curved or straight) lines. If this is not the case, as the differentiation between Figure 6.a and 6.b shows, a relationship is not defended, or participants argue that the relationships are mediated by some other variable. All of this suggests a deep-seated assumption and mundane sense—which has existed since the early Greek philosophers—that nature and mathematics are isomorphic, that is, that the world is fundamentally mathematical. Thus, if there is not a ‘clean’ relationship between two variables—if all data points do not fall onto a line—it is assumed some other variable is mediating the relationship or that a relationship just does not exist.

[Insert Figure 6 about here]

Ordered Table

Five participants constructed tables of ordered values; all individuals ordered their tables on the basis of the approximate coverage; one individual also constructed a second table in which the data pairs were ordered according to the second variable.

There is not an overriding correlation between the light and density of brambles. Areas with 1250 fc and 1200 fc respectively, have 15% and 40% density, respectively. Question: Could soil content or pollution, slope, drainage, have an equally strong effect on plant distribution? The proximity of the areas of low density would indicate a spill (killer) or type of adjacent soil that does not enhance growth. [Tammy]

Four of the five individuals suggested that either the investigation needed to be re-done or that additional measurements on other variables possibly mediating the relationship were necessary (including nutrients present, soil type, moisture, moisture retention, animal predation, pollution, slope, and drainage).

No Data Transformations (Verbal)

Without a transformation of the data into some other mathematical form, it is difficult to make claims about the relationship between two variables under consideration, and therefore contribute to the construction of a phenomenon (which here would be light fosters plant growth). In contrast to our earlier research which had shown that both preservice secondary science teachers and Grade 8 students split their claims with respect to the existence of a relationship (yes/no), in this study all respondents who did not transform the data claimed that a relationship did not exist between light intensity and bramble density. The following answer was provided by Tilson (honors B.Sc. in biology, environmental science)

- It is difficult to draw conclusions on patterns from these field notes because she has broken the data up into small sections—so it is difficult to make conclusions.
- I don't perceive any patterns between % of bramble cover and the amount of light.

- The use of % bramble cover is misleading because it is referring to different area sizes.
- The highest bramble coverage seems to be along the left and bottom sides of the study area—perhaps this is an edge of some kind, or perhaps there is a path of bramble running along this edge. The light is strongest along this edge as well, except for along the weird slanted side—perhaps this is a building or wall which is blocking the light.

In addition to the problems of perceiving patterns from the raw data on the map, this participant also argued, in contrast to general practice, that the relative coverage is a function of the plot size. However, it is not clear whether in this case the argument drove the claim or if the argument emerged after a pattern was not detected. As many other individuals who claimed that there was no direct relation between the two variables, Tilson then sought patterns in the geographical distributions and then hypothesized about possible natural features (i.e., other factors) that might cause such a distribution.

Other solutions

Two solutions did not fit into our previous scheme and were, because of their limited frequency, categorized as “other.” One individual re-drew the map to scale including three cross-sectional lines and beneath it, plotted the average bramble coverage against location. In this way, she engaged in the construction of “transects,” a common practice in ecological field work related to plant distributions (see next section).

Collaborative Readings by Preservice Elementary Teachers

We don't know enough information to make many patterns.

Among the preservice elementary teacher pairs we found similar claims and quantitative arguments as among the preservice teachers (secondary) with bachelor degrees. However, as is seen in Table 4, the number of quantitative comparisons was lower (in relative and

absolute terms), and between (rather than within) strategies were predominantly used. As before, the comparisons between CF, DE, and DH made for the bulk of the numerical comparisons. One individual proposed the existence of two subareas, in each of which there was a different kind of relationship.

Yeah, GESTURES[D<—>B] like if it was to say that these are all correlated there's some kind of connection with these at the top or there is something at the bottom, it just don't go either, I mean, 'cause 10% should be 750 whereas 40% is 1200.

[Erna]

[Insert Table 4 about here]

In contrast to the instructors with B.Sc. degrees, the preservice elementary teachers made many comparisons in which one or both measures were compared on qualitative grounds.

Because here's 1250 [H] and 1200 [D], which are very similar, and there's [H], that's [D] like more than twice as much. This [C] is 0 [F] and 30 [C] right, so we can't really see a pattern between the light and the percent of brambles. [Etta]

You're going up here [H,G] in this stretch And you go from pretty much the same amount of coverage, pretty close, but there's a huge amount of light difference.

[Ella]

In these cases, the comparisons are not based on ratios. Erin first compared the coverages of C and D, and achieves as result "10% less." She then compared this to the "half the amount of light." In Etta's case, the H and D areas are "very similar" in terms of light intensity, which is compared to the "more than twice as much" in coverage. The argument of similar then carries over into the comparison of C and F (each 500 foot candles), but with drastically different coverage. Ella's argument also rested on a comparison of similarity in one measure (they are both 30%), whereas on the other measure, "[E] got way more light than [C]."

“Maybe It’s a Pathway or Parking Lot or Something”

In four of the five groups, numerical and qualitative comparison of the measures predominantly occurred during the first half of each session. Thereafter, the task definition appeared to change from seeking a relationship between the variables to one in which students attempted to explain why Elizabeth might have obtained the particular measures she had. When it gets complex problem solvers, whether copier repair people or economists, appear to use narratives (Bruner, 1986; Orr, 1990). Explaining the geographical distribution of the light and or bramble coverage:

I think there must be a pattern in here maybe with the source of light, because if we’ve got, for some reason, it seems to be going this way [E—>D] and then when it breaks of that [west] way then [east] it’s less, you know what I mean, because we got 15 [E], a 1000 [A], a 1250 [H] and a 1200 [D] and then when you go.
[Erin]

The groups generally focused on the geographical distribution of light intensity and bramble density. In four groups, participants elaborated on possible effects due to the movement of the sun, blockage of light by objects (hill, rocks, fence) or plants (trees, brambles in neighboring plot). One major concern in these groups was the lack of brambles in Plot F leading to varying reasons being proposed: sidewalk, compost heap, cement patio, rock outcrop, parking lot, yard, pond, and rocky cliff or slope were proposed as possible features that did not permit brambles to grow in this plot. Among the factors considered more generally which might mediate the growth were differences in soil quality and type, depth of soil, ground water, water received through rains or sprinkler systems, and competition by other plants (weeds or trees) crowding out the brambles.

“How did they measure the foot candles of light?”: Questions of Method

Three respondents wondered about the areas and suggested that their shape was possibly determined by the percent coverage. For example, some wondered whether the shape of Plot D was determined by that area in which the average coverage was consistently 40% (Erin, Eli) or because the plots are “separated by the amount of light they receive” (Eva). Erna suggested that in her experience, sampling areas were either round or square, but never irregularly shaped. Others suggested possible features such as pathways (Erna, Ed) that might have determined the particular shape of the plots. In two groups, participants asked for reassurance that the maps were correct and whether these maps actually corresponded to the research area. There was also a question whether the light measurement was read appropriately from the instrument.

Discussion of LFN Solutions

This part of the study showed that whereas scientists all defaulted into the same practice (transformation of data into Cartesian plot, statistical analysis, outliers), the (preservice) teachers enacted these practices only when primed with a similar activity. Even then, only a minority (26%) engaged in best-fit or trend analysis. That is, at this point, most (preservice) teachers do not enact the default interpretive practices which we observed among the scientists. One evident difficulty affecting the teachers’ interpretations was that the data did not fall on a neat line but were scattered. Variation of one variable for the same or similar values of the other were used as evidence to argue that covariation did not exist in the data set.

The most discussion of individual data points (quantitative and qualitative taken together) occurred among the pairs of preservice elementary teachers (5.2 per group); fewer among the instructors (4.0 per individual); and least among the written answers from the preservice secondary science teachers (0.4 per individual). An analysis of how the

comparisons of the data points were deployed in the argument shows that the predominant number of these (31 numerical, 9 qualitative) were used to argue that with same or similar measures on one variable, there was considerable variation on the other (Table 5). Fewer comparisons were used to either argue that there was a pattern of the type low light:low coverage:::high light:high coverage (7) or that there was an inverse relation indicated: When two data points are compared, an increase in one variable associated with a decrease in another variable was made three times.

[Insert Table 5 about here]

Arguments against a relationship between light intensity and bramble density based on the comparison of individual data pairs shares similarities with the model-based reasoning employed by college students on algebra story problems (Hall, Kibler, Wenger, & Truxaw, 1989). Our participants in this category reasoned directly within the situation glossed by the problem rather than relying on mathematical formalisms. They proposed a relationship and then used specific instances in which the hypothesized pattern was violated, or used a specific instance as counter argument for a relationship. Table 5 indicates that, if qualitative and quantitative comparisons are considered together, there was a considerably larger number of within variable comparisons than between or cross variable comparisons ($\chi^2(2) = 22.8, p < .0001$).

Our participants' search for the firm association between variables is not something that should be attributed to some cognitive deficit, for there are long-standing traditions among scientists themselves whereby firm, ideal associations are thought to underlie worldly phenomena. Early astronomers, and particularly Ptolemy, added an increasing number of circles (epicycles) in order to maintain a model of the universe based on circles. Just as our participants introduced additional factors to try and clarify relationships, Ptolemaian astronomers added additional epicycles to bring their models closer to the data points. Furthermore, recent evaluations of the research on the effect of cholesterol was mired in

long, never closed controversies because scientists believed that close associations should exist, but no research ever could establish a clear relationship:

The scientists conducting these studies were looking for the sort of diagnostic signal which was characteristic of pre-World War II medical success stories—that is, a certain blood cholesterol level that was as firmly associated with heart disease as was the tubercule bacillus with tuberculosis or high blood sugar with diabetes.

(Garrety, 1998, p. 733-734)

Thus, underlying the discourse of many of our participants is an epistemology that the world can be mathematized in a way that makes for perfect explanations of the data (granted that they are “good” data). However, we do not claim that people actually “hold” such beliefs. Rather, even people who have never thought about these relations, drawing on cultural resources to which they are consistently exposed (such as the media), and possibly because of “common sense,” will make claims that are consistent with such an epistemology. The claim that scientists believe in the isomorphism of nature and mathematics (Lynch, 1991) should be expanded to include at least those populations from which our participants originate—(future) teachers of science. But whereas scientists know from (research, laboratory) experience that data almost never fit ideal lines, our participants did not have such experiences. Thus, our explanation for the answers provided by our research participants focuses on the differences in the habitual practices in which the different participants engaged rather than in differences in cognitive ability. This contention is further elaborated in the next section which shows that even practicing scientists may experience difficulties when it comes to interpreting line graphs that do not come from their own domain.

Findings II: Interpreting Transformed Data

Our second research question concerned the interpretation of data when these were already expressed in the form of a graph, that is, “How do (preservice) science teachers

interpret a graph from published research?" The Plant Distribution graph (Figure 3) is one which originated in the scientific journal literature, but which is also found, in a transformed fashion, in undergraduate science textbooks and lectures (Bowen & Roth, 1998a). Thus, asking participants with science backgrounds to interpret such a graph is an "authentic" activity in that it is one in which they would normally engage, as part of their reading of scientific writings, as they learned about science. This particular graph is also conceptually consistent with the Lost Field Notebook task as both deal with a correlation of two measures. However, they are also different tasks in that in the Plant Distribution task the transformed representation is already complete and has been "cleaned" so that variation is minimized and the best-fit lines are generally consistent with the caption. By adding the caption, we constructed a task that had a high degree of similarity to the ordinary activities of scientists than would using a graph without the caption. Even those participants who had little familiarity with journals inferred that the scientific literature was the source of the graph. As one preservice elementary teacher suggested, "Maybe there is an article that goes along with it where it says something about the plants being important for something or other." Furthermore, a pilot study suggested that without a caption this graph was virtually meaningless for all members of a group constituted of graduate students of education and mathematics education professors.

Semiotically-Informed Phenomenological Hermeneutic of Graphs

In research on graphs and graphing from a sociocultural perspective, we have evolved a semiotically-informed phenomenological hermeneutic to frame, describe, and explain the process of interpretation (Roth, 1996; Roth & Bowen, in press; Roth, Masciotra, & Bowen, 1998; Roth & McGinn, 1997, 1998). A phenomenological hermeneutic undertakes to rebuild, from the beginning, the conditions necessary for the understanding of graphs as cultural units which semiotics—and traditional cognitive science (e.g., Larkin & Simon, 1987; Tabachneck-Schijf, Leonardo, & Simon, 1997)—accepts as data because

communication functions on the basis of them. Such an approach is necessary because our research showed that graphs, even for practicing scientists, are often highly ambiguous “things” that have to be constructed as a signifying object with particular features before or as part of constructing possible referents to which the sign refers. Phenomenology therefore refers perception back to a stage where signs are no longer confronted as explicit messages but as extremely ambiguous texts akin to aesthetic or biblical ones (Eco, 1976; Ricoeur, 1991).

[Insert Figure 7 about here]

We view the interpretation of graphs as a dual, not necessarily sequential process which (a) establishes the graph as a sign which (b) stands for some phenomenon in the world (its referent). In the first process, the graph as a sign to be constructed is an object in the world which itself has to be structured (Figure 7; top left). That is, the graph is a referent for the structuring processes that establishes its nature as sign and its specific feature. The result of the second process is a phenomenon in the world that stands as a referent to the graph as sign (Figure 7; bottom right). Our work shows that during graph interpretation, the two processes are interwoven such that both graph as object and graph as sign are concurrently constructed in a cyclic and mutually constituent fashion (Roth, 1998; Roth, Masciotra, & Bowen, 1998). Interpretants are of a different nature and can be: an equivalent sign vehicle in another semiotic system, (drawing of mountain) synonym, translation into another language (“Berg”), emotive or metaphoric association (mountain = purity), a scientific or naive definition in the same semiotic system (mountain = natural elevation with steep sides), or an iconic representation of a mountain (e.g., Fuji). The work of sign-interpretant relation is to elaborate the sign-referent relation. In this section we illustrate different levels of reading by (a) a professor who knows the type of research and the graph intimately well, (b) other scientists who know the type of research, (c) (preservice) teachers who mainly

construct the graph as a signifying object and engage in literal readings, and (d) two scientists who discarded the graph as meaningless.

Readings by Scientists

*We can see the effect of these different types
of metabolisms on distributions of plants*

Distribution graphs are relatively familiar to most scientists. Yet reading a graph is not a straight-forward activity, and it depends on the level of familiarity with the referents of axis labels and objects identified in the graph, that is, with the dimensions that span and constitute the new (virtual) space, and on familiarity with the research methods that lead to such graphs.

For the ecology professor (Sen) familiar with the research from which the graph was taken, the graph was actually transparent such that he hardly referred to it at all, but talked about its “meaning,” that is, the ecological discourse into which it inscribes itself.

We can see the effect of these different types of metabolisms on distributions of plants. Here we have a moisture and elevation gradient and a transect which is actually an elevation gradient but here elevation is closely associated with moisture and temperature. The low land, it's more or less desert, it's very hot and dry. You get higher up in the mountains and it's cooler and wetter. [Sen]

Here, Sen does not begin with a reading of the graph, but prefaces his description by an overall statement about the purpose of the graph. These are the kind of readings we often get when individuals thoroughly familiar with the particular topic “read” the graphs or diagrams that they are thoroughly familiar with. However, our research also shows that the same scientists who are not thoroughly familiar with a topic have to expend (sometimes tremendous) efforts to construct the meaning of a graph or, as we show below, abandon all interpretation before integrating this graph into their familiar discourses.

Sen, who has been teaching an introductory ecology course for several years, provided us with a “literal” reading of a particular aspect of the graph, the position of the distribution maxima.

This [graphic] is just showing you the distribution of numbers of plants that have different types of metabolisms. Where it is coolest and least dry [$C3_{max}$], relatively more C3 plants. Where it is sort of intermediate here [abscissa $C4_{max}$], and intermediate temperature, intermediate dryness can have relatively more [$C4_{max}$] C4 plants. And where it is extremely hot and dry [abscissa CAM_{max}], because this is South Texas after all, we have relatively more [CAM_{max}] CAM plants. So these metabolic differences happen to have strong effects on distribution of the plants.

[Sen]

This type of graph is frequently used in introductory ecology courses. For example, resource utilization along some niche parameter and specialization (adaptation) which expresses itself as population density variations along the adaptation parameter are commonly found types of distribution graphs (e.g., Ricklefs, 1990, p. 732, 752). In fact, Ricklefs (1990) shows several distributions of flora species along moisture gradients: deciduous trees along a moisture gradient in Wisconsin using “average importance values” as the ordinate dimension (p. 687); Oregon and Arizona with a biomass measure, stems per hectare, as indicator for “importance” (p. 666); and hypothetical graphs distinguishing open and closed communities along an environmental gradient which is, in the text, exemplified in terms of a moisture gradient (p. 659). In the original article from which the Plant Distribution task was drawn (Eickmeier, 1978), photosynthetic pathways as the major means by which ecological resource (niche) division occurs in plants along a moisture gradient was the key point in its interpretation.

Thus, without much work of reading the details of the text (graph, caption), Sen provided us with a reading of the significance of this graph in the domain of his research and teaching. Rather than some cognitive aspect that distinguishes him from the other scientists, his greater familiarity with this kind of graph, and this graph in particular, is a more reasonable and simpler explanation. Our conjecture, about the importance of habitual engagement in graph interpretation in settings where it is common practice to engage in such domain-specific activities, gains increasing importance as we provide our analyses of the other practicing scientists, and in particular those who found the Distribution Graph meaningless and difficult to interpret.

Reading the Distribution Graph

For scientists who were less (or not) familiar with the topic (photosynthesis), domain (botany), or research methodology (transects), interpreting the graph was a more protracted effort.

Here [abscissa] is your elevation. So you're taking some kind of a transect that goes up the mountains. And down in the valley you have warm dry climate and as you go higher you're getting cooler temperatures and a little of precipitation and cloud formation and as a result something is zoning itself out. [Sid]

In the first structuring move the abscissa is made salient. At this point, the graph is characterized by an abscissa with the particular feature of having elevation as a referent. In his next move, Sid found a referent in the world (of his experience), the abscissa standing for a worldly situation where making transects by sampling along some geographic parameter is done. Sid drew directly on his experience, which includes collecting samples in oceans, of some phenomenon distributed both horizontally (geographical distribution) and vertically (depth distribution). Furthermore, as he described the transect moving up the mountain or down into the valley, he also associated these with the experience of changing "climates" associated with such moves.

In the same way, Sam invoked the changing climates and fauna that can be directly experienced on the West Coast, or on any trip into the Rocky Mountains, Alps, or other mountain ranges. Ira (an “Instructor”) talked about a trip across Mount Kenya from semi-arid plains on one side through plantations of coffee into the cool mist, and Sid articulated a zonation of those things to which the distributions refer. In Vancouver (Canada), for example, both zonation and climate differences are visible during many parts of the year when there are barren, snow covered peaks on the mountains and blooming, even exotic plants in the low lands. Here, the salience of elevation was used to construct vivid images and descriptions of natural settings. Scientists make sense, that is, link the representation with their other understandings and experiences (“so it, just as you go up it gets colder and wetter, that makes sense” [Sally]). In this case, “sense” to Sally meant that there is a preservation of the structural properties of the graph in which the graph can be read as indicating higher = wetter and cooler—which is consistent with her experience.

So, it’s showing some kind of zonation that whatever C3 is it likes, it dominates at these higher altitudes, C3, it’s kind of, it’s a minimum and it actually picks up down at the bottom. So, there’s a bi-modal distribution in this. That’s CAM that may have a zone in the middle, on the upslope where it reaches a maximum and doesn’t grow anywhere else, or doesn’t live anywhere else. And C4 is a weakly bi-modal, it has a peak there [left] and a major peak [C4_{max}] there so you’d find C4 dominating, well not dominating because C3 is dominating but it’s relatively high at mid elevations. [Sid]

Here, Sid constructs the graph as an object which can refer to something else. He is concerned only with the particular features, the location of the various peaks and valleys with respect to the elevation, and with respect to the relative frequency. As to the latter, he distinguishes between “dominating” and being “relatively high,” in which the C4 peak is contextualized and therefore relativized in two different ways. In the first, “it is not

dominating” sets the C4 peak in relation to the C3 graph at the same abscissa location; in the second, the C4 peak is read relative to the other points on the C4 graph. The ecology professor (Sen) who was familiar with the research that had led to the graph never entered this stage of the interpretation.

OK, so they “predominate in the hottest, driest environment” but why they drop off at the hot, why they didn’t go up there, that’s a question I have about it. [Sid]

Here, the opposite to making “sense” occurs. At this point, the graph appears to be inconsistent with the caption text which indicates “predominates in the hottest driest environment” whereas the graph shows a drop in the relative importance. Sid appeared to say, “I cannot make sense of this feature of the graph,” that is, he could not integrate it into what he already knew or what the other parts of the text (graph, caption) told him. Testing consistency did not only move from graph to experience or inference, but also the other way around. Sally first suggested, “I assume these things [C3, C4, CAM] don’t all live at the same level?” but then rejected that assumption as she inspected the graph which showed values unequal to zero for each of the graphs (“these guys are actually all existing at each of these elevations. It must be, obviously”).

I guess CAM are succulents. . . they are obviously very good at holding moisture. I mean, plants that live in hot drier areas tend to be very good at it, they’ve got waxy coatings on their leaves and they tend to be very good at not losing moisture when they are exchanging gas. Oh, so these guys actually have a nocturnal gas exchange for water preservation, oh cool, okay. [Sally]

Although Sally did not know about the photosynthetic mechanism and how it operated in the course of the day, she constructed from what she knew (waxy coatings) and what she read in the caption (nocturnal gas exchange) to construct a story that made sense to her.

Sid concluded with a statement about the adaptation of the plants which allow them to compete relative to other plants, or to succeed in particular climes, “So each one of these

plants has adapted some strategy to succeed over other plants or succeed in a particular temperature and moisture domain” (Sid). Similarly, Sally also concludes discussing the plants adaptiveness to the climate in which they’re found.

I don’t know what kind of plants these guys would be, I would presume they possess some, I guess, it’s not clear to what, what sort of adaptation these guys [C4] would have, but these guys [C3_{max}] are probably adapted, what’s 2000 meters, that’s fairly high, so they’re probably adapted so much to that higher elevation, certainly accustomed to a lot more moisture. [Sally]

The scientists ended with explicit statements about the adaptation. These statements arose from the scientists’ attempts to explain the contrast between the three curves associated with the three photosynthetic mechanisms. One scientist (physicist) made direct links to C3 plants as possibly being grasses or conifers, or other Alpine flowers, the kind of plants he knew from experience grow at high elevations.

The “discrepancy” that C3 and C4 plants increased in relative importance at very low elevation levels was not necessarily a salient element in scientists’ interpretation. Some scientists and the instructor noted them but did not address them at all (Sid). For example, Sam suggested that, possibly, the gradients of moisture and temperature indicated at the top of the graph may not hold at the lowest elevations or that a lake or ground water levels provided the moisture to which C3 and C4 plants were adapted therefore displacing the CAM plants.

If you see relative abundance, then you add it up probably to something like a 100. These are not independent, the three curves. Like you don’t have, you don’t have something like density that’s plotted. Then, but if you get a peak here, you necessarily get depths in the other. [Sam]

Sally, too, noted that the three graphs were not independent and suggested that the graph was not a good plot and that “it would be a lot better to plot a straight out density or

biomass or something like that, or just whatever, straight numbers, whatever you wanted to represent.”

Analysis

The scientists who read the graphical representation in this way did three dimensions of reading work. First, they read the lines in terms of their past experiences relating to a changing fauna with elevation and associated climatic changes. At the same time, they locate the three distributions with respect to each other. Finally, they attempted to explain the location of the three maxima in respect to each other by drawing on the concept of adaptation of plants to the physical environments. Their analytic work carved the reality of the graph such that each of the three relations told a story about the relative frequency of a type of plant (even if they did not know what type of plant it might be). The other dimension of their work was the relation of the text to some state in the world. First, this state is about the relationship between the frequency of one type of plant with changing elevation (or climate). In the second instance, the state has to do with the existence of ecological niches.

Instructors & Preservice Teachers

*We're just trying to determine what was the purpose
of this graph beside showing distribution*

The interpretation sessions of three instructors and four pairs of preservice elementary science teachers were characterized by their predominant focus on the nature of the graph (and almost non-existent discussion of referents in the world). Their readings were largely literal rather than being concerned with the implications of the contrast raised by the three graphs. One preservice elementary teacher's comment at the end of their interpretation, “Because all this does is tell us where these 3 points are” (Etta) in a way summarizes what these individuals and groups concluded about the distribution graph. The fifth group of

preservice elementary science teachers differed somewhat because, in a manner similar to that of scientists, they attempted to link the distribution graphs to their experiences in the desert, on mountains, and in different parts of the US. A secondary teacher summarized his analysis in a similar way:

All I can say here is relative importance whatever that's supposed to mean here for the C4 type plant, it never gets all that high at whatever elevation, the highest it gets to whatever 30 something that's supposed to be, at around 1, 2, 3, 4, 5, about 1400 meters, the CAM one varies greatly, it's much lower at the higher, jumps up to its maximum at around 800. So, I can give you some numbers, I was not entirely sure what they mean by relative importance. [Ian]

As a result, the participants did not feel particularly successful at the completion of the task. Eva suggested "If I came across this in a textbook, I would likely just skirt right by" and Eldon commented "Relative importance, I didn't get that part."

The following episode was recorded five minutes into Erica and Eliza's 27-minute session with this graph. At this point, they attempt to establish the relevance of some basic graphical features such as the additional abscissa above the graphs:

Erica: But look, it was relative importance, 40, 80 does it say anything about that?

Eliza: This is just a XY graph, not XYZ or anything, it seems strange that there's three [top abscissa], I don't know about X

Erica: Like, you know what I mean, there is this [abscissa] and this [ordinate], you know, and there is also that [top abscissa]

Eliza: Yeah, but this [top abscissa] is just READS[caption] desert and semi-desert, but it seems.

Erica: So we can even ignore that [top abscissa]? I mean, and just go according to this [ordinate] [abscissa]? But the thing is. (10 s)

Eliza: Relative importance. Well it's a distribution along a moisture and temperature gradient due to differences in elevation. So this [upper abscissa] corresponds with elevation, it's hottest, right? It's hottest and driest at 500 [500] and as you get to an elevation

Erica: OK, so that's what it is all about?

Eliza: At 2000 meters it becomes coolest and least dry because they say C3 predominate [C3_{max}] at the cooler, least dry end [upper abscissa, C3_{max}], that's what they're telling us.

Eliza and Erica attempted to integrate ("make sense of") the graphical representation—particularly the secondary abscissa indicating climatic gradients associated with the elevation gradient—with the discourses about x-y and x-y-z graphs with which they were somewhat more familiar. For example, in their first reading, they treated the correlative abscissa as a different, third dimension as it would appear in an x-y-z graph. Erica asked whether they could ignore the secondary abscissa and interpret the graph as a relation between elevation and relative importance. However, having re-read the caption, Eliza pointed out that the upper abscissa is simply correlative to the lower one and made explicit links between the elevation scale and the temperature-moisture scales (e.g., 500 m hottest/driest, 2000 meters coolest/least dry). What is remarkable about the episode is that neither Erica nor Eliza attempted to link their statements about the relations in the text (graph, caption) to their personal experience or other referents in the world that might have helped them to make sense (establish structural equivalence) and therefore increase their understanding both of the graph and the world.

Erin: READS["C4 plants are maximally important under intermediate temperature and moisture conditions."] So, intermediate and moisture, like what I would say is that the hottest and driest is going to be at that elevation?

Etta: Well, it is because, oh well just because it says that, it doesn't mean that this is the hottest and driest that's possible on planet earth (Erin: No) It just happens to be that this is hottest and driest compared to this over here, so it appears on this section right here.

Erin and Etta struggle for meaning at every step of their analysis, that is, try finding in their own experience discourses that would help them elaborate the text (graph, co-text) in front of them. In the following episode, Eldon and Eva attempt to relate the elevation (lower abscissa) and the climate variables (upper abscissa):

Eldon: Least dry. So that must, yeah, so least dry over here [$C3_{max}$], so it's cool there

Eva: I think that this is what is confusing. Like I get that [$C3_{max}$] this highest point [CAM_{max}] just when [$C4_{max}$] it's best at photosynthesis and then this [left, upper abscissa] is hottest, driest, coolest [right, upper abscissa], least dry. Then this elevation [500 m], like in my thinking lower elevation would mean, I guess not, I was thinking cooler, colder, and then higher [2000 m] elevation would be warmer.

Here, even relating the two gradients in the context of the caption appeared troublesome. Eva, who had read the caption which indicated that C3 plants do best in a cool wet climate, had trouble with her association of coolest and least dry with lower elevation. Each aspect that they identified could therefore not be taken as granted but had to be integrated with the other pieces of the graph (cum caption). In the same way, Erna struggled with connecting the ordinate construct (relative importance) and its scale to something she was familiar with:

But here, I mean, how do you connect this thing at 40 and 80, do you see this as a percent, or do you see, what do you see? These 40 mean, can it mean something?

You know what I mean, like without just looking at these 'cause these correlate right, these 500 mean hottest and like that but here. [Erna]

In the process, she attributes “hottest” to an elevation measure (500), rather than constructing the relationship as an association. In part, these student groups struggled with what appeared to them to be arbitrary associations which, in the readings of scientists, were immediately meaningful through the association with their personal experience in relevant environmental settings. Thus, although the preservice elementary science teachers found themselves in the same situation as many of the scientists (i.e., not knowing about this aspect of ecology) the preservice elementary science teachers appeared to struggle with each element, the meaning of each process (CAM, C3, C4), whether these labels stood for individual plants, types of plants, or processes, what the referent of “relative importance” might be, and so forth.

Another reason that difficulties arose in interpretation of graphs was because of the interpretation of words in non-canonical ways. “What I was thinking is that, the importance of the C3 being at coolest, least dry at 2000, it’s very important that it would occur there, you know what I mean?” (Erna). “I’m not understanding what relative importance means (pause)? I guess, important to the environment, or what?” (Erin) “This photosynthesis process which occurs in this C3 plant is not so important, there might be other processes which occur,” and “the importance of it occurring at this elevation at this dry.” The difficulty with interpretation of what the ordinal axis label “relative importance” meant contributed to difficulties encountered interpreting the graph.

Although the conversations among the preservice elementary science teachers and science instructors generally did not elaborate on worldly referents, we already described in the previous section that Ira began his session by referring to his experience of hiking up and down Mount Kenya, and the changing climates and flora associated with this trip. There was also one group which, to a much lesser extent, attempted to link the graphical

representation to places they had already visited. Also in the following quote is an example of participants reaching conclusions which, although not necessarily incorrect, were not relevant to the biology of the plants in the problem at hand. Here, Eli linked “thinner air/atmosphere” with lower moisture levels, a fact that contradicted what he had read from the graph and caption.

Eli: I think of elevation as well, you go up higher there is less, there’s thinner air, thinner atmosphere means generally less moisture because there’s less air, so there would be less water in the air. It’s harder to breath the higher you go up, because there’s thinner air, it would mean less (Ella: Less moisture?) Yeah it’s true, there is snow up there, but it is pretty frozen, I don’t know if that counts as moisture, I don’t know, it might. I guess it precipitates, it’s snow, but it’s snow moisture.

Ella: Well, the further north you go in Canada, the climate is generally quite dry so I guess, in those terms, but the elevation is not that high.

Eli: But this is Texas too, which is just generally warm. I’ve not gone, I’ve been to California, I haven’t been to Texas, I’ve been to the central area of the States, yeah, or the eastern part of it.

Before that, Ella had already talked about a visit to the Californian desert and her experience of the large temperature variations and the relative dryness; she furthermore noted that cacti had to be well adapted to such a climate. But neither she nor her partner generalized the adaptation argument to the other types of plants described in the caption and to the graph as a whole.

Although the discourse in these groups generally stayed within the context provided by the graph/caption, there were three brief instances in which comments addressed issues of adaptation and survival. Yet, every time, the significance of these issues was never pursued

or became salient; they generally appeared as passing comments and remained unelaborated and little connected to the interpretive task.

But the thing is if you look at it, none of them are at the same elevation, so they all predominate too at different elevations which allows better survival as well.

Because they're not fighting for area and they're not fighting for the resources in that area. [Erin]

It just looks like you have three different plants, each photosynthesis method makes it more suitable for different environments, so as you could, go through the gradient, you get different plant populations predominating. [Ed]

These comments were the only ones in the entire sequence related to the Distribution Graph in 1596- and 749-word sessions, respectively. These were not culminating comments that summarized the activities, but were strewn in the middle of their talk about the nature of the graphs.

Other Scientists' Interpretations

I knew that it wasn't very meaningful, it was just trying to show visual patterns that were detached from reality

Two of the scientists refused to engage in a school-like activity and critiqued the graph from the perspective of their own work. In both cases though, they provided nearly transparent readings of their own graphs which had appeared in research journals and reports (Roth, Masciotra, & Bowen, 1998). Both provided us information at the end of the interview or sent us information afterward on how to prepare better graphs than the ones we had used in the research with them.

I knew that it wasn't very meaningful, it was just trying to show visual patterns that were detached from reality. But when I see this sort of thing here, it's important to me to understand what the scales are so I can read. Because this is in theory

something that is very real, so they draw a lot of these [abscissa] scales. I look at this and I can sort of forgive it because there's absolutely *no* information at all about, you need sort of far more explanation. [Sandy]

It is evident that their difficulties have to be taken seriously. Both were successful in their professional domains and had a considerable numbers of publications. In their explanations of graphs which they had constructed for publication purposes, the graphs were actually transparent, individual features which offered them occasions to develop thick descriptions rich in detail about the contexts in which the data were collected. Yet with the unfamiliar graphs they struggled considerably and abandoned efforts of making sense.¹² The following excerpt in which Soren (M.Sc., forestry) wrestles with the “meaningless” acronyms C3, C4, and CAM illustrates this struggle.

I mean, because you've got, you're talking about relative importance, you've got 3 different species here or whatever. Are you talking about the relative importance of this one [C4] to these other ones [C3, CAM]? Or to some other external influences?

I don't know. [Soren]

Sandy (Ph.D., marine biology) similarly attempted to come to grips with the notion of “relative importance.” Both scientists struggled with the fact that they neither understood nor could relate to the ordinate label, “relative importance” and that they did not know what the acronyms C3 and C4 stood for. Although Sandy realized that the graphs were to tell a “bigger message,” he, as Soren, did not provide readings in the way the other scientists did.

¹² During our interviews, there were three other graphs in addition to the Plant Distribution graph (Roth, Masciotra, & Bowen, 1998): birth and death rates as function of population size; graphical representations of essential, substitutable, and complementary resources in the form of isographs; isobologram representing the effect of two resources for plant growth.

Discussion of Plant Distribution Graph

On this task, the split between scientists and (preservice) teachers was not as clear as on the Lost Field Notebook. Two scientists found the graphs meaningless and did not provide an interpretation. Most of the preservice and inservice teachers engaged in the construction of the graph as a sign (Figure 7, upper left) and in reading the individual curves literally, that is, as a change in the distribution of a particular plant type. They predominantly read the graphs in their relation to the abscissa (i.e., noting that there are changes of the relative importance with elevation) This is what one would have expected from the Lost Field Notebook. One of the instructors and eight scientists contrasted the different curves and therefore constructed a phenomenon that was not literally available in the graphical representation: the differential adaptation of plants with different photosynthetic mechanisms to climate. In the process of reading, the scientists drew on past experiences related to the research method that yields data as those presented and on their familiarity with questions of adaptation to construct their reading of *this* graph. The phenomenon emerged from the mutually constitutive reading of graph and constructing the elements of the graph on the basis of familiar experiences. Finally, in the interpretation of the ecology professor who used this and similar graphs in his lecture, the graph as representation became transparent. He talked about the phenomenon of adaptation and how it led to different distribution of plant types in varying climates.

Thus, we can see differences where our (preservice) teachers focused on reading the lines and indicating what relationship they express. The scientists contrasted the lines and constructed a secondary text in which the relative position of the lines had to be explained. There was one student group and one instructor who actively used past experience (trip to California desert, Southeastern and Central USA; across Mount Kenya) to enhance their grasp of the Distribution graph, that is, to increase the linkage between this previously

unknown text and other texts that they are familiar with from scientific and experiential domains of their Self, but it was uncommon.

The difference was further observable in the scientists' greater tendency to draw on personal experience (strip sampling, constructing transects, traveling up mountains) as an important aspect of making meaning, that is, constructing links between extant experience and understandings of the new graph. In this, they could test whether some relation they inferred from the graph "makes sense," that is, is consistent with another aspect of their experience/understanding.

Findings III: Data Collection, Transformation and Interpretation

The previous two sections dealt with practices of interpretation which required a transformation of a data set (the LFN problem) or of data that had already been transformed (the Plant Distribution graph). In both cases, data and graph were ready-made and the tasks could therefore be critiqued as more school-like rather than authentic (Lave, 1992; Roth, 1996). In the conduct of science research there are several practices which precede these representations, their transformation, and their interpretation—question "asking," operationalization of variables, and collection of data. In the past we have attributed that difficulty in interpreting graphs to a lack of experience in conducting these initial stages of research by the interpreter.

The conduct of effective research has several critical features which must be attended to and if students in public schools are to be expected to be able to do this type of analysis it is not unreasonable to expect that their teachers can engage in these same practices themselves so that they can best scaffold the children into and through these activities. Scientific research proceeds from the asking of "do-able" questions (Fujimura, 1987). These questions must have variables "identified" which must then be operationalized so that data can be collected. Various representations/transformations of the data then occur and from

these claims are made which, generally, refer to the original questions asked.¹³ The following analysis structures and orders the questions, design, representations, transformations and claims made by secondary pre-service science teachers (with science degrees) in their research project reports, highlighting the approaches used in each area and points at where there are inconsistencies in the chain of argument between one section and the previous section(s).

Analysis of Preservice Secondary Teachers' Reports

To aid our analysis and interpretation of the work done in the reports, we used the following analytic frame to examine and interpret how closely the reports of the Pre-Service teachers paralleled those of “typical” scientific reports. Generally, this frame evaluated competence in conducting and reporting research as this relates to the stages evident in the epistemological vee that the pre-service secondary teachers used. In our analysis, we evaluated the projects submitted using the following set of questions: (a) What is the nature of the questions? (Correlational, relational, causal); (b) Are the constructs and variables operationalized effectively?; (c) How are data represented (e.g., tables)?; (d) What data transformation techniques have been used (e.g., graphical inscriptions)?; (e) What interpretations of the data are made?; (f) Are consecutive steps in the inquiry (a through e) consistent with each other?, and (g) Do the interpretations address the focus questions?

A cursory examination of the preservice secondary teachers' reports suggests that they contain the fundamental components of scientific research reports: questions, data tables, graphs, interpretations and claims/implications are generally all present—as one might

¹³ Various authors have pointed out that the written outcomes of a scientific study may result in questions being presented as if they were the ones originally asked, although they developed post hoc as the study progressed, or even in the formal interpretative stage when the actual research was concluded. Regardless, a scientific study is generally written about in a manner which gives the appearance of internal consistency and coherency from the original framing of the “question” to the “claims” about that question.

expect them to be given that the epistemological vee provides prompts for these elements to be included.

To examine these reports in greater detail we independently viewed the reports and coded them into the representation seen in Table 6. Each student report was summarized in the table by highlighting (i) what type of question was being asked (Column 1), (ii) what the variables were (Column 1), (iii) how the variables were operationalized (Column 2), (iv) how the data were represented (i.e., maps and tables; Column 3), (v) what transformations were used (Column 4) and, (vi) what claims were made (Column 5). As well, symbols were used on the table to indicate when variables weren't measured in such a way that they could be compared, when transformations didn't relate to the original questions, when inappropriate graphs were used, and when claims did not relate either to the data or to the original question. Our closer analysis revealed that in the details of the research work there were many instances of non-standard approaches to the research and inconsistencies in the analysis of the data (Table 6 details ninety such problems). Generally, there were: research questions unanswerable by the study design, constructs inappropriately operationalized, data reported and transformations (graphs) used inappropriately, and claims which frequently did not match research questions or the data reported. Table 6 was ordered so that reports with the scientifically most acceptable practices and interpretations of data were at the top and those with the fewest at the bottom. We first summarize the findings and then use a representative student report from the top, middle, and bottom third of the table which we elaborate in detail to examine the use of various scientific practices in the field projects and the internal consistency of the reports.

[Insert Table 6 about here]

Structuring Research Questions - Design Issues

When the pre-service secondary teachers first entered the research area (located in “undeveloped” mixed forest at the edge of the university property) there was considerable

discussion in the student pairs about what “do-able” questions they were to investigate. As students continued to work on identifying the area in which they were going to conduct their research work, staking out boundaries, and drawing a map of the zone, they started formulating specific questions to address as they noticed more and more specific details of the zone and reflected about the equipment which had been made available to them.¹⁴

Many of the investigations were framed as “causal” investigations—of the twenty-four questions addressed by the students fourteen were causal. For example, some of the causal questions asked were, “How does the moisture level affect the distribution and height of horsetails in our investigative site?” (Table 6, Question 3.b.) and “Do the exhaust gases from the cars parking in Lot C directly effect concentration of field flowers in front of the lot?” (Table 6, Question 11.a.). In the first case, two components of the question indicate that it is intended to address causal relationships. Firstly, asking “how” indicates causality and, secondly, assuming the directionality that it is the moisture which affects the horsetails, not the horsetails affecting the moisture level (as is the case in some plant species), indicates that the intent of the question is causal not correlational. The second example is also clearly causal in intent because of the directionality implicit in the question as field flowers could not affect the release of “exhaust gases from the cars” but the exhaust gases might affect the field flowers. Note that for both questions it is not that directionality/causality can not be demonstrable, but that the temporal structure of the activity (two field periods within 8 days) make a causal investigation unfeasible.

Operationalization of Variables

Being able to appropriately/defensibly operationalize variables in a study is a key step to being able to construct claims from the data collected. If variables are poorly

¹⁴ In this, their discourse was similar to that of the grade eight students we observed work on similar field-based science activities (Roth, 1996; Roth & Bowen, 1993, 1995). For the field-based activity in the present study, the preservice teachers had the same equipment available as that used by the grade 8 students in the earlier study.

operationalized, then it is usually impossible to make claims that relate back to the original focus question(s). Of the student reports, several (seven of twelve) studies had problems with how they operationalized their variables and/or with replication or sampling (Table 6; second column). In part, this was the result of addressing questions which were difficult to operationalize involving, as they did, biological factors such as “competition,” “biodiversity,” or “productivity” that are ecologically quite complex (and abstract) and which often require long-term studies and data collection. However, problems with operationalization of variables also occurred in situations where these conditions were not present in such a way that they would interfere with effective operationalization.

An example of effective operationalization of variables is found in the first study (Table 6; Questions 1.a. & 1.b.). In this study, to address the questions, “Do spittle bugs show host preferences for three dominant plants in the plot?” and “Is there a relationship between light intensity and the distribution of [plant species] in the plot?” the preservice secondary teachers: (i) identified locations of individual plants of the three species; (ii) counted the number of spittlebugs on “ten stalks of each plant at five randomly chosen sample sites”; (iii) graphed the average number of spittle bugs found (with error bars) for each type of plant; (iv) measured light intensity in a grid across the entire mapped area; (v) drew a pattern map with the light intensity indicated over which was laid the locations of the [plant species]; and (vi) made claims related to the original focus questions using the data set collected and depicted in (i) to (v). This sequence effectively operationalized the originally stated focus question.

In conducting our analyses, we decided to highlight instances of problems with operationalization which were apart from those of causality being inappropriately addressed (indicated in the previous section). Two major types of problems with operationalization were highlighted: (i) the measured variable ineffectively reflected the conceptual intent of

the initial question, and (ii) there was insufficient replication or an inappropriate sampling regime.

One particular study will be used to illustrate both of these situations. This study (Table 6, Question 12.a. & 12.b.) addressed the questions, “How does the side of a fallen log affect it’s biodiversity?” and “How do the burned portions and the recent and older exposure of new wood affect the snags biodiversity?” To address both questions “biodiversity” was operationalized as the “frequency/quantity” of different types of organisms—lichen, moss; small plant growth (non-lichen, moss); spiders; beetles, larvae; and insects. Counts for lichen and moss in different areas were indicated as whole numbers ranging from one to five; no indication was made as to whether this enumeration indicated patches of the plants or individual plants (which, given the setting, is highly unlikely) or how this related to patch size. In this study, a count of “2” insects in a section represents large (macroscopic) insects visible at the surface, not those beneath the surface of the soil, under plants, in logs, etc. In this case, insufficient operationalization and sampling meant that even correlational claims based on data as it was presented would be inappropriate.

Representing Data

Data was represented or depicted in the reports in two main ways: in “maps” (which were requested as part of the assignment) and in tables. All reports included a map representation and 14 of the 24 focus questions had data summarized in a table. Several of these tables were structured in non-standard ways and did not aid in understanding any patterns that may have been interpretable in the data. For the reports that did not use a table, using a table would have aided interpretation. Indeed, for the questions that were being addressed, using a data table in the collection process might well have led to more effective data collection. Our ethnographic field work with ecologists highlighted the role that tables served in their work—less as a representation tool than as one which “reminded” them what data they needed to collect (Roth & Bowen, 1998). In the practice of field science, tables

serve as a tool which organizes researchers' thinking towards the focus questions and what data needs to be collected. Observations made of students in their lab activities during this course suggested that they viewed tables as a representation/presentation tool and not as an integral part of organizing the research before and as it was being collected.

The maps in reports occasionally served as a surrogate for tables by helping the report writers relate variables. In three of the reports the maps were not sketches of the landscape upon which data sampling sites were recorded but were instead grids onto which measurements, locations of plants, or counts were recorded. Three other maps were diagrammatic sketches detailing plant locations and physical locations onto which measured data (e.g., light levels, moisture levels) were inscribed. The remaining six reports contained maps which detailed plant and substrata distributions but which were not used to indicate any measured features from the focus questions. Thus, it was not possible to use them to examine relationships between the biotic and abiotic variables under study—in essence, these maps served as iconic representations, “pictures” of the site, but contributed little to the investigation of relations being conducted.

Transforming Data: Using Graphical Inscriptions

Use of graphical representations occurred in almost all of the reports (10 of the 12; one of those that did not may have been able to more effectively interpret their data if they had). However, there were many problems with how graphs were used in the reports to depict the collected data. One report used line graphs when bar graphs would have been more appropriate for the data, three reports used bar graphs when scatter plots were more appropriate, and one report used a one-dimensional bar graph when a 2x3 bar graph would have better illustrated the data set. In one case, further insight would have been gained if an X-Y-Z plot had been used. Even when scatter plots were used (five times), best-fit lines were drawn on only two of them, and in one case was placed incorrectly. An outlier, which might significantly affect interpretation, was noted in only one case, although in the

previous example (of the trend line being misplaced) identifying an outlier would have affected interpretation of the graph.

Apart from the broader concerns of appropriateness of representation, graphs were often labeled or structured in ways that confounded their interpretation by the readers and were often inadequately (or not) discussed in the text of the report. For instance, one graphical representation depicted “gradient” and “change in moisture” on its axes, but was not referred to in the text of the report nor discussed in the “methods” section and was therefore lacking interpretive context.

In several student projects labeling of the maps, tables, and graphs was such that they contributed little to understanding what these inscriptions were representing. As a result, readers had to spend considerable time trying to relate written “claims” to the various inscriptions in an attempt to understand how the claims were derived. This lies in contrast to typical writings of science in which there are clear cues and pointers between report text, captions, and labels which together help the reader constitute and construct for themselves the claims from the data which is being presented. Understanding derives from reflexively cycling back and forth between the text and the inscriptions relating those pointers to ones own experiences. As labels, titles, and text become impoverished so too, subsequently, does the understandings which readers derive from them.

Four graphs were drawn which were unrelated to the questions being addressed, and in some instances there appeared no conceptual reason to construct some of the graphs (such as plotting a bar graph of averages of measures across a slope). In total, 6 of the 10 reports using graphs¹⁵ had problems with how they used graphical representations to depict the

¹⁵ Whether it was appropriate (in our view) to utilize a graphical depiction for a particular data set when one was not used was not a consideration in this critique. The total was derived from conceptual issues arising from graph usage—not part of this total was any critique of structural difficulties such as poorly labelled axes, poor titling, or non-discussion of the graph in the text.

collected data with a subsequent effect on the claims drawn from those representations (Table 6).

Interpreting Research Data

The conclusion of a scientific report attempts to draw conclusions about patterns in the data collected/represented and discusses data in the context of the original question(s). This is often followed by a discussion of implications of the data, any issues arising from the design of the study being reported on, and future questions which might be addressed. The epistemological vee prompted the preservice secondary teachers both to include graphs and interpretations of those inscriptions in the analysis of their data. In our constructive critique of the claims section of the reports we therefore focus on the interpretations of the data being reported on (both graphs and tables) and how these interpretations relate to the original question(s). Our analysis examines the graphical representations and analyses used to report on students' own research work in contrast with analyses of the Lost Field Notebook and Plant Distribution graphs.

Several of the reports had interpretations which clearly followed from the collected data and its representations and transformations. However, many other of the reports made claims unrelated to the original question(s) or which did not logically extend from the data collected/depicted. Of these, the latter is the most problematic and occurred in ten of the twelve reports (Table 6), in some reports with regards to one claim, in others with regard to all of the claims made.¹⁶ Also, in five of the reports, claims were made which were not related to the original question. For example, one report concluded that "intraspecific and interspecific competition affects the growth, density, and distribution of plants" drawing this causal conclusion from a dataset lacking measures attributable to "competition" (a quite

¹⁶ Errors were not "double counted" in our analysis. For instance, if "slope" was operationalized inappropriately for the scientific meaning of the term and indicated as such in column 2 of Table 6, the interpretation of slope data in the claims section was viewed as being "inconsistent" or "consistent" in relation to the data which was collected, not in relation to a correct operationalization of "slope."

abstract ecological concept) or of “growth.” However, in only two cases was this done and the original question also not addressed (in two other cases no claims were made related to a question posed in the study at all). No statistics were calculated in any of the cases nor was mention made that they could be calculated for the correlational data. Overall, problems with the claims’ sections arose more frequently from claims made which did not extend from the collected data, a quite frequent problem, rather than from claims which did not address the original question.

Detailed Analysis of Three Cases

To gain further insight into the competencies of the pre-service secondary teachers holding science degrees in standard scientific investigations we conducted a micro-analysis of three of the reports. In this analysis we examined the structure of the questions, the recording and reporting strategies, and the final claims for internal consistency and the methodological approaches used using the analytic frame detailed above. Table 6 is ordered such that reports with the most canonical approaches to research and reporting are found at the top and those with the fewest at the bottom. For this micro-analysis we chose one report from near the top, one report from the middle, and one report from the bottom of Table 6. These reports ranged from one that asked correlative questions, operationalized variables effectively, represented the data effectively, and drew claims related to the original data to a report which addressed causal questions, inappropriately operationalized variables, used inappropriate representations (of the collected data) and drew inappropriate conclusions (from the collected data).

Case # 1 (Table 6; Questions 2.a. & 2.b.)

This report addressed the focus questions, “Is there a relationship between the maximum height of the horsetails and the density of the horsetails?” and “Is there a relationship between the maximum height of the horsetails and soil moisture?” To answer

these questions, students staked out a 4 m by 5 m area with string in 1-metre square sections and drew a detailed map of its plant biota. Moisture was determined by repeated measures in each 1-metre quadrant to the “depth of the horsetails’ tap root.” Horsetails were “counted in each quadrant” and the height of the “horsetails in each quadrant was determined and recorded.” (Details of data presentation and interpretations are found in Figure 8.)

[Insert Figure 8 about here]

In our reading of the report we noted that both questions addressed correlations and were answerable in the physical and temporal context within which the students worked. The operationalization of the variables was consistent with the original questions (i.e., the questions dealt with horsetail height and density and soil moisture, and these were the data collected and tabulated). Data were inspected and one set of plants excluded from analysis as it appeared to the participants that they were misclassified and would thus confound or mislead interpretation.

This report used two Cartesian graphs (Figure 8b & 8c) which allowed answering the focus questions. What lacked in these graphical inscriptions, in comparison to the work of practicing scientists we observed during and after this fieldwork, were lines of best fit and statistical evaluations of the relationships. Conducting linear regression analysis would have revealed that the linear relationship between height moisture had a regression with $r = .75$, $p < .008$ and the linear relationship between height and density had a regression with $r = .65$, $p = .023$. This analysis was not done (which is not unreasonable since statistical analysis was not requested in the assignment), however, if it had been it would have strengthened the final claims (Table 7) made in the report. The first claim pertains to the original question asked, yet the speculation as to the correlation between height and density appears is not the only one possible. The second claim is a reasonable inference because

high transpiration from some plants can lower local moisture levels.¹⁷ Though the report does not discuss these explicitly, some of the “additional questions” (e.g., “how soil type affects soil moisture”) allow the inference that the reports authors were considering these issues. Overall, this report showed a strong internal coherency, such as is found in formal scientific documents, from the original questions which were framed to the claims which were drawn from the data.

Case # 2 (Table 6; Questions 7.a. & 7.b.)

This report addressed the focus questions: “How is moisture related to the slope of the hill?” and, “Is the clustering of the ferns related to the moisture in the soil?” To address them the students marked out a 4 m by 5 m plot and “drew a scale map of the plot including plant types and location” and then “divided plot into 20-1 m² sections.” They then “took moisture readings in every corner and the center of each section, at 4 cm depths.” “Slope” was operationalized by measuring distance down the slope from the highest elevation of the marked out plot. (Details of data presentation and interpretations are found in Figure 9. Letters A - E represent cross-slope co-ordinates, numbers 1 - 4 represent down slope co-ordinates.)

[Insert Figure 9 about here]

The questions in this report are structured to examine the relationships between two variables are ineffectively operationalized and the data sets not juxtaposed so that these relations can be determined. “Moisture” was operationalized as ‘average soil moisture,’ slope as ‘distance down slope,’ and fern counts or density not determined or represented in ways which allowed comparison to the independent variable of moisture. Observations

¹⁷ Another reasonable interpretation from a biological perspective would have been that favorable conditions allow both increased distribution/height and density which therefore covary without having to be the cause of one another.

such as the locations of plant species were recorded in a scale map (represented in part by Figure 9, Data (a); No key was provided) which could have been used for comparison with the measurements of average soil moisture in each of the 20 quadrants (Figure 9, Data b).¹⁸ One characteristic of traditional science practices found in this study was the replication of measures of moisture reported in Data b.

Data was then transformed into the representations seen in Figure 9: Transformed Data 'a' & 'b.'¹⁹ The Transformed Data 'a' bar graph represents the average moisture in the five sample strips (each with 4-1 m² plots) across the slope. This bar graph is neither discussed in the text of the report nor does it address any of the questions being addressed thus there seems little theoretical reason for its inclusion. The figure shown as Transformed Data "b" represents the average moisture "down" the slope of the plot. We asked two ecologists to examine the graphs and they noted that because of the "relationship" that was initially framed as a question they would have chosen a Cartesian x-y graph to represent the data.

To address the second question our ecologists said they would have plotted the values of all measurements of moisture, or at least the average from each of the 20 plots, in a scatterplot with fern counts in each quadrant. However, such a graph may not have been possible (from the data included in the report) because there was no measure of fern density at the field site other than that in the site map that was drawn. If this map were "to scale" (as the report indicates) and the "F" markings indicated individual fern plants (this was not explicated) then such a graph was possible to construct. Finally, the bar graphs, which depicted means of means did not include error bars to indicate the standard error although

¹⁸ The data in Figure 9, Data c which, being unlabelled and unreferenced in the text, was at first not interpretable. After some work, we realized that Data c represented the average of the moisture readings obtained in each quadrant which were given as raw data in the table shown (in partial representation) in Data b.

¹⁹ Neither of these representations are explicitly related to the "slope of the hill" focus question (bar graphs are not used to illustrate correlations; although such a relationship may be read into Transformed Data b), and neither are related to the second focus question.

these were calculable from the data available. As indicated in Figure 9, there was little labeling of the figures and no captions were provided (which complicated our interpretive analysis of the inscriptions).

The report's first claim (Table 7) was stated as a "relation" (top, middle, bottom) as opposed to the correlational framing of the original question. A statistical analysis of the correlation from Data c, suggested to be a normative approach by our field ethnography work with ecologists, shows a correlation coefficient of $r = .66$, $p = .0014$; F tests for the four distance categories would yield $F = 7.01$, $p < .004$). Hence, the report understates the conclusion which can be drawn from the data which was collected.

The report's second claim, that "pattern of fern placement on the slope is not related to moisture content of the soil," is difficult to interpret because, other than the visual clues which can be taken from the scale map regarding plant distribution, there are no numerical data to substantiate the claim. The ecologists we asked to view this report suggested that it be better to operationalize "fern placement" along the slope so that it is a quantity thereby allowing statistical estimates of Type I and Type II errors allowing the claims to be situated. Finally, the text of the interpretations/claims were unelaborated providing little guidance as to how the graphs and information in the report should be read. Our research on scientific journal articles (which most of these students would have encountered in their third and fourth year courses in science) found that graphical inscriptions were considerably elaborated with text both in the caption and in the "claims" and data sections of journal articles together mutually constituting the claims and reducing ambiguity in the reading of the inscriptions. Elaboration of this sort does not occur in this report making the reading of the report and interpretation of the inscriptions much more difficult.

Case # 3 (Table 6; Questions 11.a. & 11.b.)

This report addressed the focus questions: "Do the exhaust gases from the cars parking in Lot C directly effect concentration (measure of productivity) of field flowers in front of

the lot?” and “Do the exhaust gases from the cars parking in Lot C directly effect height (measure of growth) of field flowers in front of the lot?” To address these questions the students “selected a level area of flowering plants in parking lot C” and measured out a “4x5 m area” which was subdivided “into m^2 sections.” Each quadrant “was examined for growth and productivity of flowering plants.” Productivity was operationalized by counting “each bud/bloom . . . rather than the stem.” The “height of each flower was measured using a metre stick.” (Details of data presentation and interpretations are found in Figure 10.)

[Insert Figure 10 about here]

Our reading of the report found several issues that were problematic. Both focus questions seek to establish causal relationships between a physical variable (presence of exhaust gases) and the biological variables “concentration” (used as a measure of productivity) and height (as a measure of growth). As written there are conceptual and definitional difficulties with the focus questions being addressed. First, presence of “exhaust gases” is an inference about the effect of the proximity of the parking lot (as stated). Such a connection between “exhaust gases” and proximity to the parking lot would typically be an inference drawn in a “claims section” if proximity to the parking lot was found to be significantly related to growth of the field flowers. Such a claim is also complicated because a busy road (alongside D quadrats) paralleled the parking lot (alongside A quadrats) on the opposite side of the study area. Thus, interpretation of the effects of the independent variable of “exhaust gases” is confounded because it is present on both sides of the research area.

There were further problems in the students’ conceptualization of variables. Firstly, as generally used in biological research growth is not operationalized by examining height. More usually, growth means either changes in height over a period of time or the population density of a species of plant. As well, productivity is normally interpreted as a

unit output per unit time and not “concentration” (more appropriately referred to as density) as was measured in this study. In addition, the “unit output” would normally refer to the number of plants, not the numbers of “bud/bloom” as were counted. What the report writers actually seek, and what their data allow them to make claim of, are relationships between distance to the parking lot and the biological variables of height and plant density.

In the report data was inscribed in three ways: in a map, two tables, and two line graphs (with strip averages joined). The map depiction (e.g., Figure 10, Data a), isomorphic in its informational value, contained data points corresponding to the actual count of the number of lupines found. This data is then reproduced in a table which is rotated ninety degrees (not shown) having “averages” calculated for the number of lupines in 1-m wide transects (parallel to the parking lot)—although calculating these is of little utility given how the data is utilized in the graph (structured similarly to Figure 10, Data c) and their calculation may have even contributed to the points of average being joined rather than a trend line being drawn. The height data are similarly entered on a table (Figure 10, Data b) with a calculation of average height across the A-D bands. However, this average distorts the data because it is an average of the average heights in each quadrat and therefore quadrats with low number of plants are overemphasized in averages for each band. The drawing of the line joining the averages further distorts any relationship because of the inclusion of the zero-value quadrats (A-1 & C-1) which bias the average value downwards. In analyses such as these it would not be unusual for these zero-height averages to be considered outliers and be excluded from an analysis of average heights.

The participants transformed the data in a categorical fashion using a line graph with the average height in each band connected—a plot of average counts and heights per “quadrant”—not as a trend line in a scatterplot as the data would have allowed. If distance from the parking lot was the independent variable, as the study suggests, then the appropriate Cartesian graph would have included it as a variable. There was also a lack of

variable names on the abscissa and brevity in titling/labeling which meant that, as with Case # 2, the representations were not embedded in a thick descriptive context which would help scaffold the reader into interpreting the data in the manner desired by the report writers.

In the report, other than calculating the average height across each of the five plots there were no statistics calculated. Both ANOVA and correlational analyses²⁰ might have offered better insights into what patterns were apparent in the data, but neither were conducted. In addition, in the calculation of averages in the report no consideration was given to what our ecologists might conclude were data outliers—in both quadrant A and C, there are “zero” values for growth (based on no lupines) which may have warranted exclusion as “outliers” and which influence the interpretation.

Claims are based on data which could have established a relationship between the distance from the parking lot and the height and number of plants. However, the interpretation that “smog” has this relation is not supported by the data given that “smog” is present on both sides of the study site because of the presence of a busy roadway opposite the parking lot. Therefore, the claim (Table 7) that “smog decreases . . . growth. . .” is unsubstantiated given the data that was collected. Claim 3 acknowledges that the presence of a busy street on the other side of the research site might have had a mediational effect on the productivity (i.e., “total # of buds/blooms”) but left undiscussed why this would affect the number of buds/blooms but not the number of lupines (i.e., “growth”) present, which was at their highest number next to the roadway. Claim 4 further confuses interpretation by the reader because what seemed to be the dependent variable under study (i.e., “smog”) is then implied to be something that the investigators wanted to control (as “control” was discussed in the class and mentioned in reports).

²⁰ In this instance we are unable to offer post-hoc analyses because only summarized data (averages), based on uneven cell size, were given in the report.

Discussion of the Authentic Investigation Task

Much like the middle school students in the initial phases of previous studies (Scardamalia & Bereiter, 1992; Roth & Bowen, 1993), and despite their previous (for most) science degree(s), these preservice teachers had difficulty constructing productive questions to direct their inquiries. The practices of our preservice teachers were also surprising in the light of the fact that practicing scientists ask “do-able” question, that is, questions that can be answered within the set of contingent constraints under which they have to work. Our present research suggests that their university courses have not assisted them in the development of a sense for distinguishing do-able from not do-able research questions (c.f., Bowen & Roth, 1998b).

The majority of the focus questions investigated in these reports focused on causal and not correlational questions (Table 6). In the context of the activity in which they were engaged, investigating causal questions was generally not feasible being more commonly addressed either in experimental situations or over a considerable period of time—neither of which were possible in this activity. In our past work with Grade 8 students conducting similar (although long-term) field research activities outside we also noticed (unreported data) that their initial investigative questions were often causal. Further, of the 25 focus questions there was some difficulty with operationalization of one or both of the variables in 17 of the questions which would ultimately cause difficulties with claims made in the reports.

These problems are similar to those found in the initial field work projects conducted by Grade 8 students. For instance, the focus questions addressed by the preservice secondary teachers had many similarities to those framed by the Grade 8 students when they first started their outdoor research—many were so conceptually “broad” that it would be difficult to address them in a single outdoor session. These questions addressed issues that were quite ecologically complex, relationships such as “competition,” “biodiversity,” “growth,”

and “productivity” all of which have specific meanings in biology that do not equate to “distribution,” counts of limited numbers of organisms, or “height” as they were used by the pre-service secondary teachers.²¹ This meant that even some of the questions which were stated as a correlation (e.g., Q4.b.) were conceptually actually causal questions because of the concepts involved in the question and how they would need to be operationalized to be addressed (e.g., competition and plant distribution; Q4.b.).

In science it is common practice to record data in tables, for organizational, process, and presentation reasons, and then to transform the data into more abstract representations allowing for the examination of relationships between variables (e.g., Figure 1). Since these studies were to be an examination of measured relations and since the vee-map heuristic prompted for the use of graphs it was not unexpected that tables and then higher order transformations would be frequently used (14 and 15 respectively of 23)—a slightly higher use of graphs than was found for the Lost Field Notebook problem. However, as discussed earlier, there were structural problems with both the graphs and tables resulting in difficulties in interpreting them. This would then compound difficulties in interpretation given that in the Lost Field Notebook and Plant Distribution activities described earlier we documented pre-service teachers having interpretive difficulty even when contextual cues in the form of suitable labels and titles were provided. Also, although only 44% of the respondents drew graphs in the Lost Field Notebook study, those which were drawn were scatterplots—which allowed interpreters to examine patterns of relation between the variables. However, in the reports of the outdoor research project 10 of the graphs which were drawn (to address 8 of the focus questions) were inappropriate for the data and question being addressed. Transforming data into a graph from a structured table is a normal step in the conduct of science and might partly explain why there were

²¹ Investigations of causality in ecology often involve experimental designs (as opposed to just observational ones) and occur over considerable periods of time sufficient to address factors such as plant growth, long term growth, competition, etc.

discrepancies in graph use in the projects compared to the interpretations of the Lost Field Notebook problem. In the Lost Field Notebook problem numbers were clearly in pairs which, given that students learn about scatterplots being used for “pairs of data” from Grade 8 onwards, lent themselves to being depicted in a scatterplot. However, in the cases where graphs in the reports were used inappropriately, data was drawn from maps where “pairs of data,” such as in the Lost Field Notebook map, were much less obvious. How one structures the data in representing it—how the data tables are structured—appears to influence the graphical inscriptions which result.

Similar to their work in the Lost Field Notebook activity, the pre-service secondary teachers rarely identified outliers and excluded them from analysis which, as shown in Case Study #3, could affect interpretation. Furthermore, lines of best fit were used in only two graphs (in one case seemingly opposite to the pattern, in the other drawn through averages and not raw data) which was a frequency even lower than that reported (26%) used when interpreting the Lost Field Notebook data.

However, just as we argued that tables do not play the role for these students that they do for experienced researchers we conclude that transformed inscriptions also play a different role. In part, this claim arises because of the discontinuity that exists between the text of the claims and the inscriptions. Whereas for experienced researchers the claims and the inscriptions are mutually constitutive, in the majority of these reports claims did not derive from the inscriptions. When examining transcripts of interpretations of the Plant Distribution graph it was clear that scientists used the graphs as a point around which to discuss claims (such as is found in its caption) relating both to their experiences in the field. In the pre-service teacher reports on the Authentic Investigation task the claims only rarely related to the inscribed data and often did not relate to the original question either. This is unlike the coherence found in scientific reports which are written to show questions clearly leading to data which clearly lead to inscriptions which clearly link to the claims which

address the original questions. Such a continuity was not present in many of the reports submitted by the pre-service secondary teachers.

If these reports were based on field studies that were expected, by the instructor, to be in-depth, lengthy, and conceptually complex then the number of non-standard approaches and interpretations present in the pre-service teachers' reports might well be understandable. However, the assignment was little different than that done previously with grade eight students who were learning to conduct their own research projects as part of their regular science classes. In spite of the substantially greater education of the pre-service secondary science teachers, they exhibited no greater competency at structuring, conducting, and writing about this type of research activity than the Grade 8 students initially did. Similar difficulties, such as asking causal questions, inappropriately operationalizing variables, inappropriately using graphs, and constructing claims that extended beyond the data initially were not uncommon amongst the Grade 8 students but became almost negligible as they gained more experience in conducting and presenting their own research. The contrast in their competency at engaging in such tasks compared to the student teachers should have considerable implications for teacher education programs.

Discussion

In this study we had participants engage in a number of different tasks which, together, were quite similar to the panoply of practices in which scientists engage as they conduct their everyday work. The tasks progressed from analyzing data (such as students would do in a biology course in which they were learning about the practices of science or scientists would do when reading scientific reports), to interpreting data which had been analyzed and transformed by others (such as students and scientists do when they read research papers written by others) to a project in which participants conducted, analyzed, interpreted and drew conclusions from research of their own design (such as scientists do in their everyday work). In these activities there were both similarities and differences between the

practices of working scientists and those of both pre-service teachers and science instructors. However, in general, the teachers and instructors did not often engage in the same practices nor reach the same conclusions of those who were experienced in conducting, summarizing, and analyzing research (including both working researchers and the Grade 8 students from our past work). It would seem that engaging in research projects of one's own design (with all of the components of analyzing and drawing conclusions from this work) is an important component of learning to interpret the work (i.e., writings) of scientists in the ways in which they intend—and this was something which had not been done by the instructors or pre-service teachers. We now discuss some of those similarities and differences and the underlying concepts of significance.

From World to Sign (Text) and Back

According to Latour (1993), nature and its representations can be thought of as lying on an open continuum which, one side, is characterized by increasing levels of locality, particularity, materiality, multiplicity, and continuity and to the right, is characterized by increasing levels of compatibility, standardization, texts, calculation, and relative universality. What scientists (and others doing research) accomplish are transformations of ontologically different representations linked only by consensus on the process and products of transformations between different inscriptions. Our tasks can be mapped onto this continuum to show the different nature of each task (Figure 1). In the Lost Field Notebook, the task requires participants to transform the data into an inscription to the right, and then to reconstruct a nature setting in which the data might have been collected. In the Distribution Graph, the task was to read the graph as a story that had a referent in the world not only about the distribution of plants, but about the adaptation of plants to particular environments. Finally, in the Authentic Inquiry tasks, participants were asked to go full circle—rather than reconstructing environments from texts (graph/caption), they actually know the setting about which they were to make some general statement. Thus,

despite the fact that the task involved more steps, it might have been easier given that they were making a statement about an ecozone with which they had personal experience.

Although the (preservice) elementary teachers did not translate their data in the Lost Field Notebook task, and therefore had little to say about the overall relations between the two variables, they did reconstruct possible scenarios that could have led to the particular data they had in front of them. On the other hand, the Distribution Graph led one group of preservice elementary science teachers and one instructor to make explicit links to their personal experiences related to changing fauna with changing climates and elevation; most activity remained referentially isolated in the context set by the sign structures (words, data, lines).

Scientists had a singular set of practices for dealing with the Lost Field Notebook: plotted the data, proposed regression analysis to test goodness of fit, discussed an outlying data point, and suggested the collection of additional data to increase the power of the statistical analysis. Our past research with pre-service secondary teachers reported that they infrequently used graphs to address the Lost Field Notebook problem and in this study we found that “priming” them about the importance of using graphs to make correlative arguments resulted in an increase in graphs being used when addressing the Lost Field Notebook problem. However, even with this priming it was still only a minority of students that used scatterplots. We turned to the Authentic Investigation task to obtain further insight into why the priming was ineffective. From these reports we realized that the difficulties lay not in knowing if a graph should be used, but rather, was embedded in not knowing how to structure data and choose appropriate inscriptions to address problems.

Epistemology

Instructors and pre-service teachers acted as if a relationship had to be unambiguous, all data points consistently “in line” with each other. Here, the belief in a mathematical nature of the universe is inherent in the explanations—there did not seem to be another way. Thus,

variation in one of the two variables with constant second variable, or a comparison of a negative relationship between two data pairs, was sufficient to reject a positive relationship between the two variables.

Where might this default practice come from? Given students' experience with science from science textbooks and lectures, and their mathematics experiences—where they likely would have been plotting functions—they would have seen predominantly, if not exclusively, line graphs and “data points” that fell, in an ideal way, on the line. In these sources there is a didactic use of clean line graphs; and in the few cases that “data” were plotted, these fell exactly on the best-fit line on the graph²² (Roth, McGinn, & Bowen, 1997).

It has been noted that scientists believe in the isomorphism of nature and mathematics (Lynch, 1991); in many cases, and for a historically long period, scientists believed that the world is inherently mathematical such that mathematical structures not only describe but in fact are responsible for the patterns in the world. Our research shows that not only scientists appear to operate as if nature was inherently mathematical. Furthermore, the very practices of using graphical representations and the mathematics activities in which functions are plotted may be at the origin of such default, commonsense and mundane assumptions about the world.

Significance for Educating Science Teachers

Overall, although the preservice secondary teachers had undergraduate and even graduate degrees in science, they did not default to practices that scientists use routinely in their everyday work. This has implications for undergraduate science education and science teacher education. As we found in the previous study where we examined the responses of teachers to the Lost Field Notebook problem, the results of this study suggest that most

²² Such a description also characterizes relationships between variables as they appear in newspapers and news magazines.

preservice teachers do not seem to be ready to teach scientific practices of interpretation in the way advocated by curriculum reform. Of even more concern was their difficulty in conducting and summarizing an open-ended research project of their own. In scientific communities participants ask do-able questions and use graphing on a day-to-day basis as default approaches to participating in the domain (Fujimura, 1987). As many of our participants had science degrees, we might expect them to default to these practices. This was not the case, and is even less likely to occur when there is less scientific training as part of a teacher education program—as occurs in many U.S. universities and colleges. If teachers have difficulty asking “do-able” questions themselves, how are they to scaffold students towards asking them so that they can effectively engage in activities which have a high degree of similarity to scientific inquiry? We suggest that not asking such questions oneself in the context of “authentic” field investigations indicates that there will not be the requisite recognition of appropriate or inappropriate questions asked by students that would be necessary to help students develop such skills. Simply telling preservice teachers which questions are appropriate or inappropriate outside of the context of their engagement in lab investigations will not increase their competence in helping students ask appropriate questions. That preservice teachers do not engage in these practices is not a critique of them individually, but rather a commentary on the efficacy of the experiences they have engaged in their undergraduate studies.

Our research has considerable implications for the preparation of science teachers. At the present, our preservice teachers did not seem to be ready to competently teach inquiry and data analysis in the way suggested by recent reform documents (AAAS, 1993; NCTM, 1989). Representing is a central part of science (Latour, 1987) and being able to scaffold students into the appropriate use of graphs and tables in the context of addressing questions which are do-able is something that teachers need to be able to do to address the curriculum reform documents. Thus, despite the considerable amount of preparatory course work that

these preservice teachers had taken in science, they were insufficiently prepared to teach in the way we would like them to. As with the telling of student teachers what “appropriate” questions are for investigation, we also do not think that simply telling preservice teachers which graphs or other tools of interpretation are appropriate will increase their competence in helping students learn canonical methods of data analysis and interpretation. We have argued elsewhere (Roth & Bowen, in press; Roth & McGinn, 1998) for changes in teaching science that would focus on graphing as social and cultural practices in which student teachers should become more engaged as part of their undergraduate science work. This should address what is clear from our work with preservice teachers and in undergraduate science classrooms—that they have little practical experience engaging in the mathematical practices of science. Structural change is needed in the undergraduate experiences of preservice teachers if they are to fulfill the goals of the reform documents and have their own students engage in the daily scientific practices of asking do-able questions and making claims based on appropriate use of various inscriptions and representations. In our social practice framework, preservice teachers need to have more experience in using graphing to help construct rhetorical claims around investigations they have designed. This would seem to be the most effective way for them to become enculturated into the practices of science which they can then use as a foundation to enculturate their own students. However, as members of a community involved in preparing teachers to go into schools and teach children, we therefore have to question (a) whether the objectives in our reform documents are realistic given the current teaching practices in colleges and universities and (b) what kind of science experiences would prepare preservice teachers with undergraduate degrees in science in a better way for meeting the challenges posed by the visions of the reform documents.

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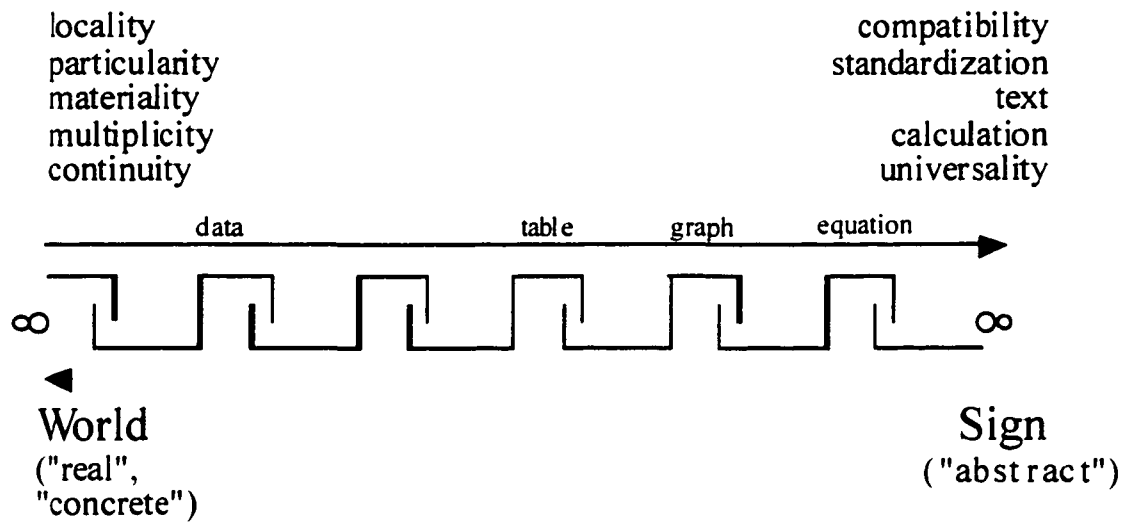
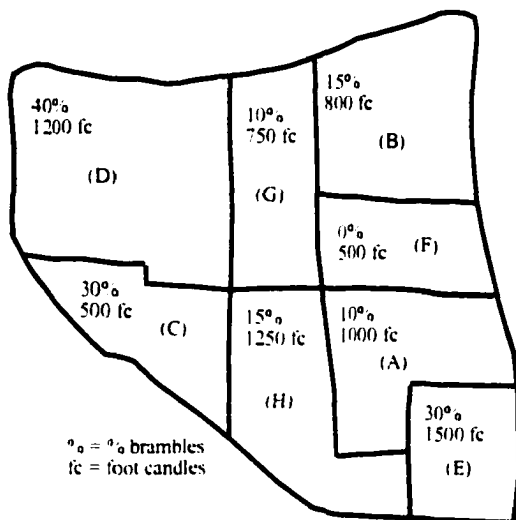


Figure 1. Relations of inscriptions between world and sign

A. Lost Field Notebook



Elizabeth is a grade 8 student who is doing research on an ecozone. She wanted to find out whether there is a relationship between the density of brambles, a plant with a long narrow stem, and the amount of light these plants receive in different areas of her ecozone. She subdivided her ecozone into smaller areas. In each area she measured the approximate coverage of the area (in %) by the brambles. For each area she also found the average amount of light, measured in foot candles (fc). She recorded her data in her field notebook in the form of a map reproduced below. Elizabeth lost her field notebook, and you found it. You wanted to know the patterns she had found, but besides the map there was no additional information. Based on the information provided,

1. what patterns, if any, do you see?
2. what claims would you make?
3. how would you support your claims?

B.

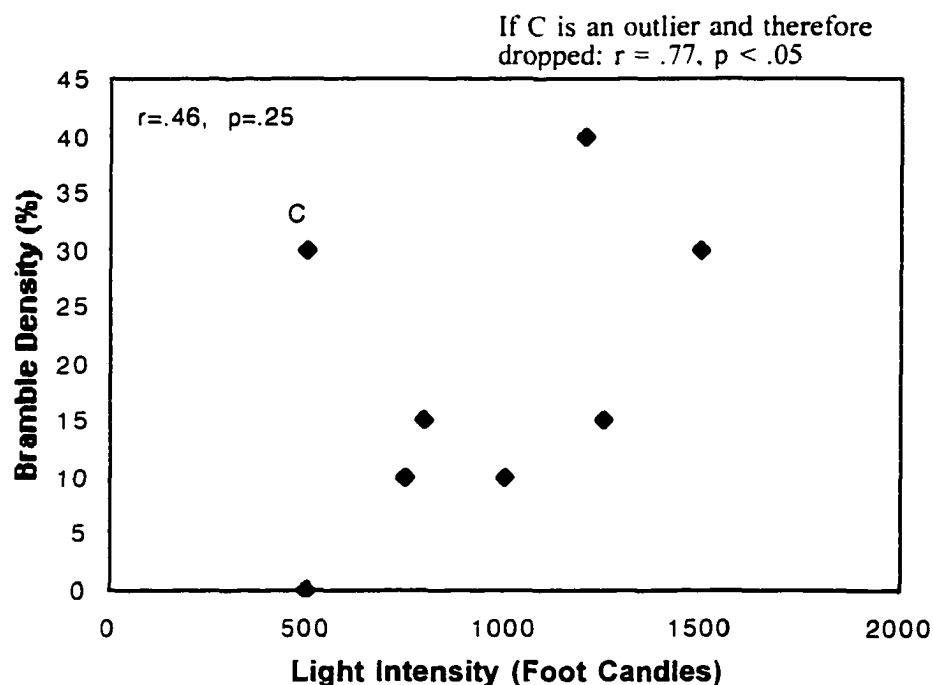
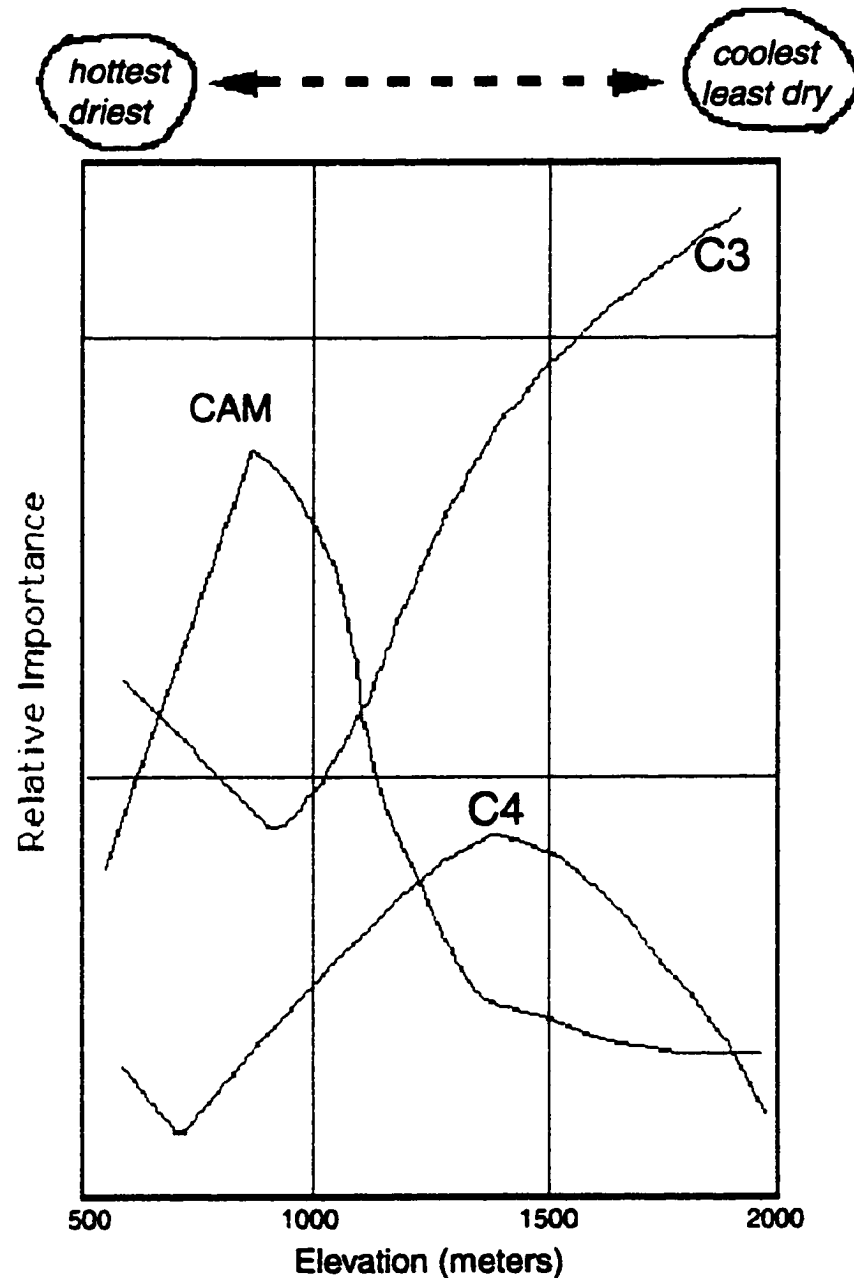


Figure 2. (a) Lost Field Notebook task, (b) Scatterplot of LFN data



Distribution of C3, C4, and CAM (succulent plants) in the desert and semi-desert vegetation of Big Bend National Park, Texas, along a moisture and temperature gradient due to differences in elevation. Cam plants with nocturnal gas exchange for water conservation predominate in the hottest, driest environment, C4 plants are maximally important under immediate temperature and moisture conditions, and C3 plants predominate at the cooler, least dry end of the gradient. (Modified data from Eickmeier, 1978)

Figure 3. Plant Distributions graph and caption

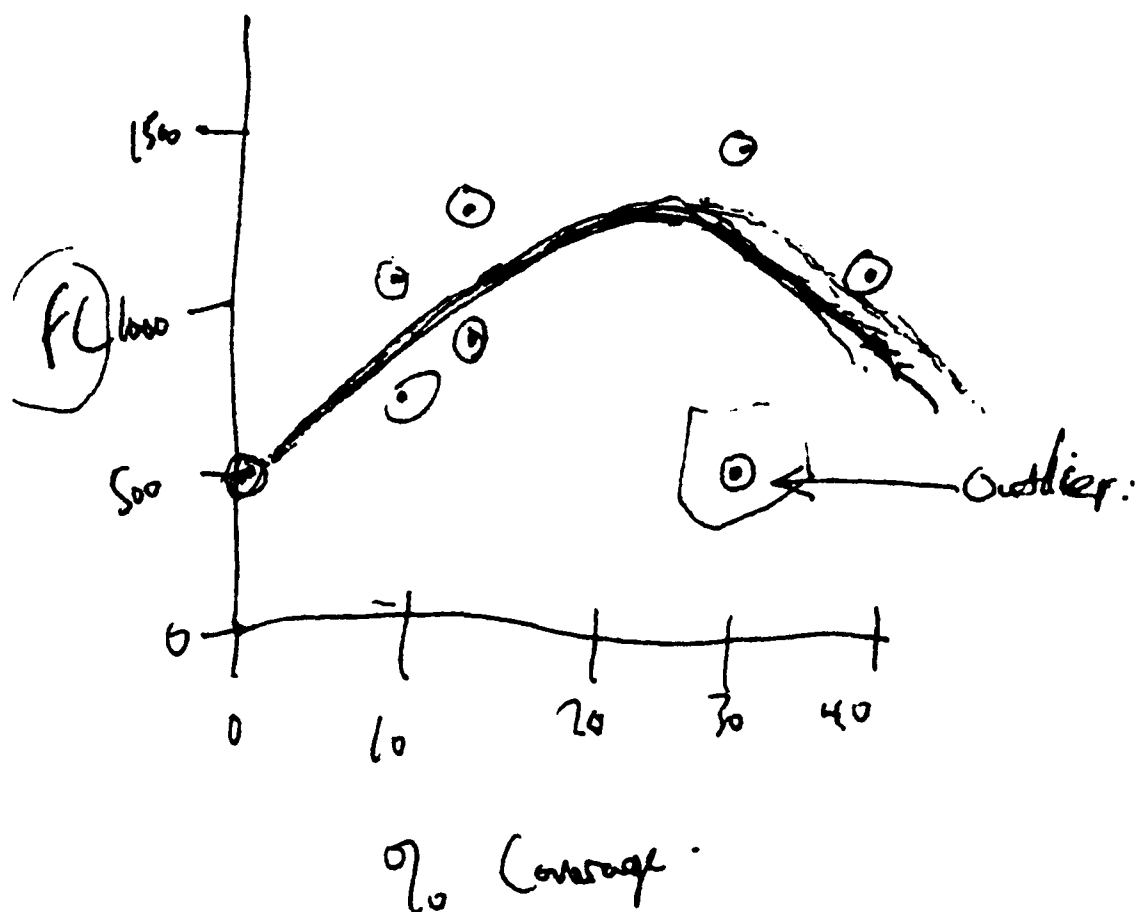
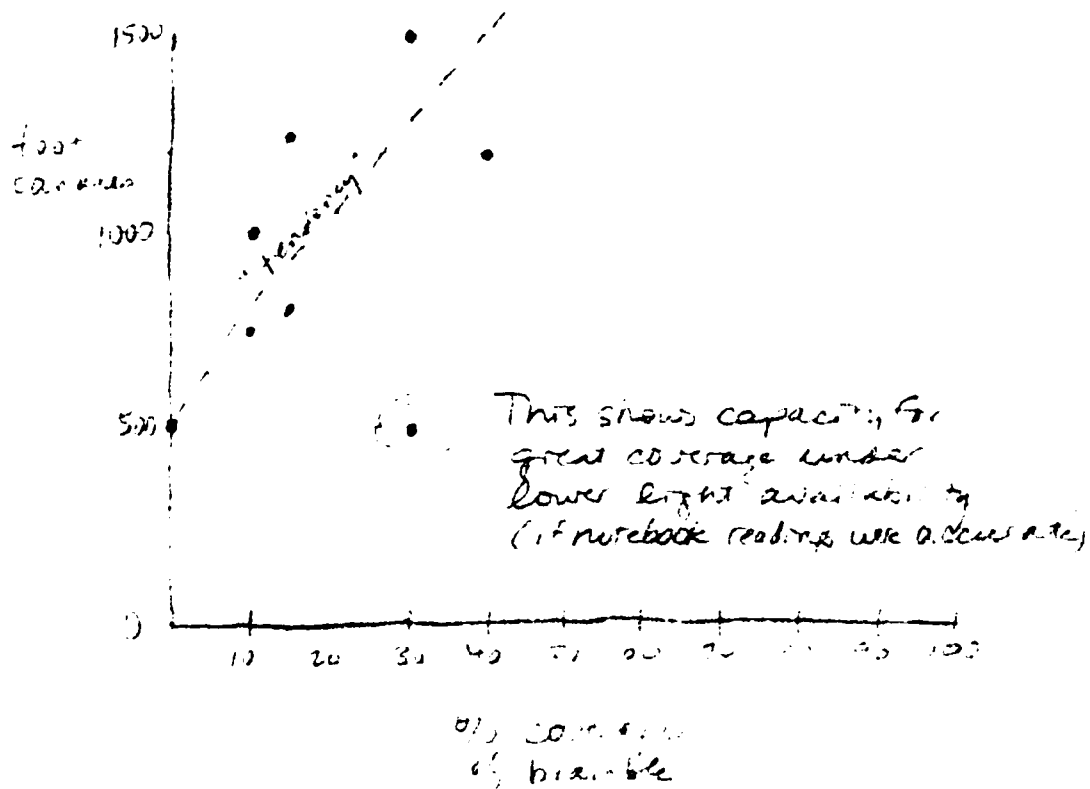


Figure 4. Non-linear scatterplot drawn by “Steve” for LFN task. “Steve” had axis reversed compared to all others who used a scatterplot to address the task.



The Lost Field Notebook

1. Patterns seen:

- "Tendency" for increase in foot candles => increase in % coverage but not absolutely shown by figure above.
- One major inconsistency: 30% coverage @ 500 f.c. but also 30% coverage @ 1500 f.c.
- Outer areas have greater % coverage, generally

2. Claims:

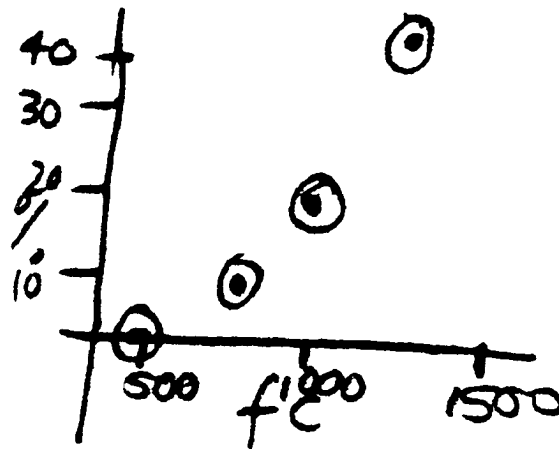
- Suggest different soil temperature, terrain types
- Suggest different water supply
- Shows plant is able to grow in lower lighting conditions

3. Support:

- From graph of data
- Must be factors other than light

Figure 5. Solution to LFN task by (pre-service) secondary teacher.

a.



b.

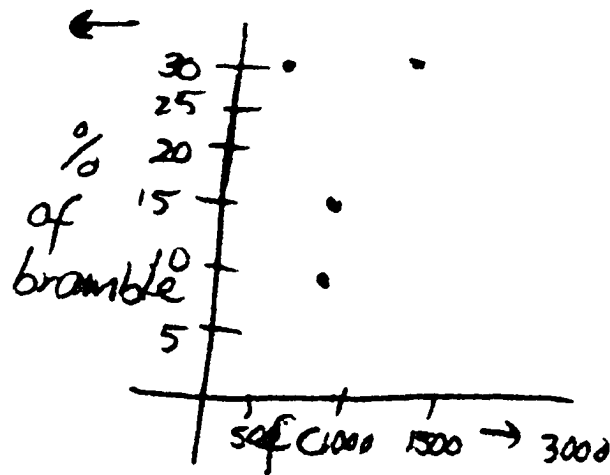


Figure 6. Solution to LFN task by (pre-service) secondary teacher who dealt with the data in two sets: (a) scatterplot of four locales for which a correlative relationship was claimed, (b) scatterplot of four locales for which a claim was made of no relationship.

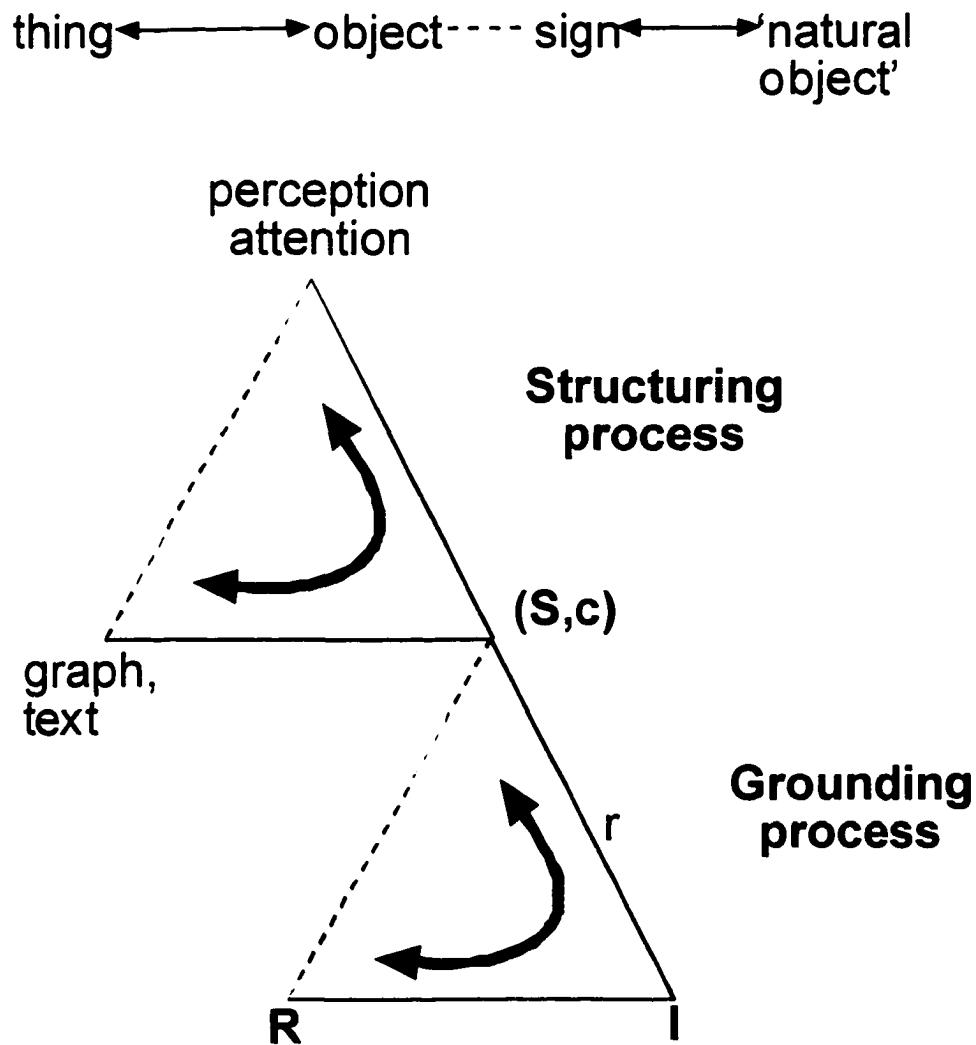


Figure 7. Semiotic model of reading graphs. The upper left hand side represents the process of perceptually individuating some element that has the potential of becoming a sign object. On the lower right hand side, signs are read as being about natural objects. Conventional constraints r on sign use, and contextual constituents c of individual sign elements mediate the reading of the graph.

Data:

Soil moisture, Mountain Horned Lizard (cm) and Horseshoe Density (100m²)

TABLE 1:

Sample	Soil Moisture (cm)	Horseshoe Density (100m ²)	Ratio (cm/100m ²)
1	7.34	28	0.00
2	7.94	18	0.00
3	7.16	15	0.00
4	7.26	15	0.00
5	7.10	15	0.00
6	7.10	15	0.00
7	7.24	15	0.00
8	8.09	25	0.00
9	6.76	14	0.47
10	7.83	13	0.57
11	8.34	11	0.71
12	8.15	13	0.61
13	7.10	15	0.47
14	7.10	18	0.39
15	7.14	20	0.36
16	6.94	19	0.37
17	5.94	20	0.30
18	7.10	21	0.34
19	6.94	21	0.33
20	6.94	21	0.33

Transformed Data:

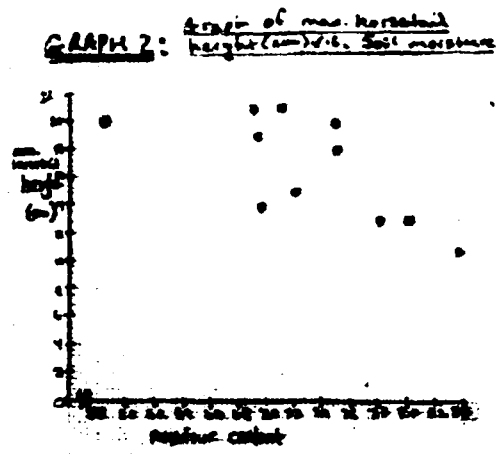
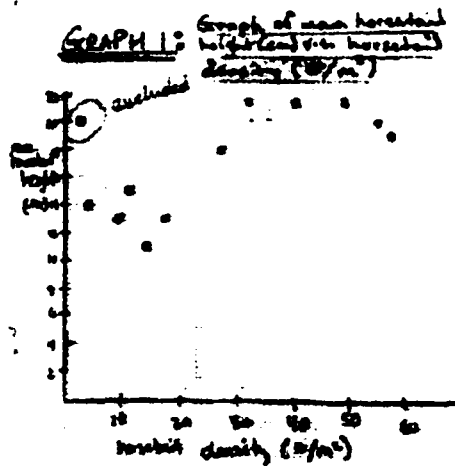
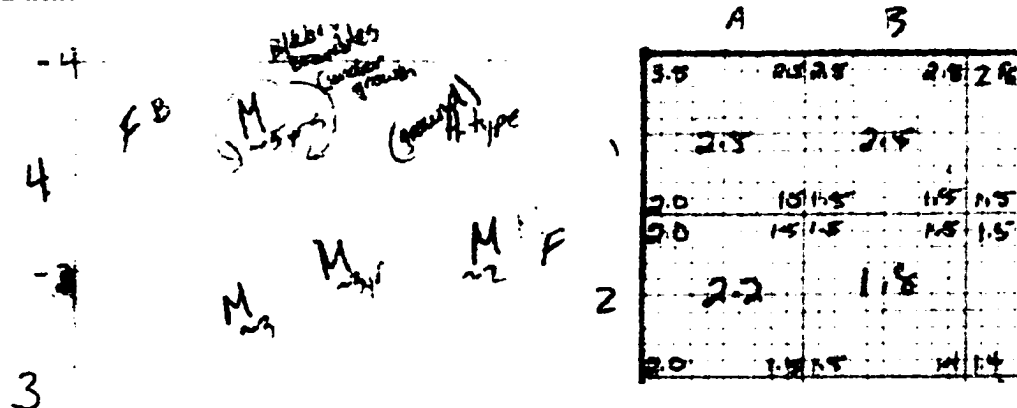


Figure 8. Scans of data & transformations from Case #1's report.

Data:



	A	B	C	D	E
1	2.4	2.2	2.2	2.7	2.3
2	1.8	1.5	1.8	2.2	2.3
3	1.7	1.5	1.7	1.9	1.8
4	2.1	1.9	1.4	1.6	1.8

Transformed Data:

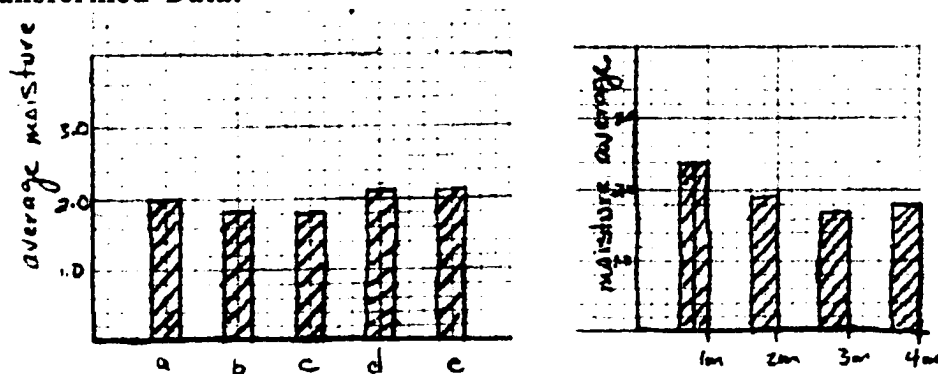
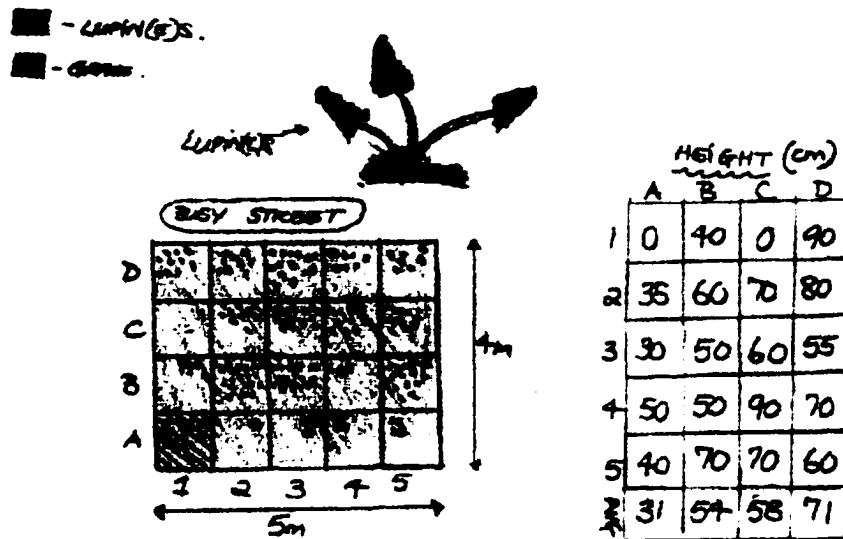


Figure 9. Scans of data & transformations from Case #2's report.

Data:



Transformed Data:

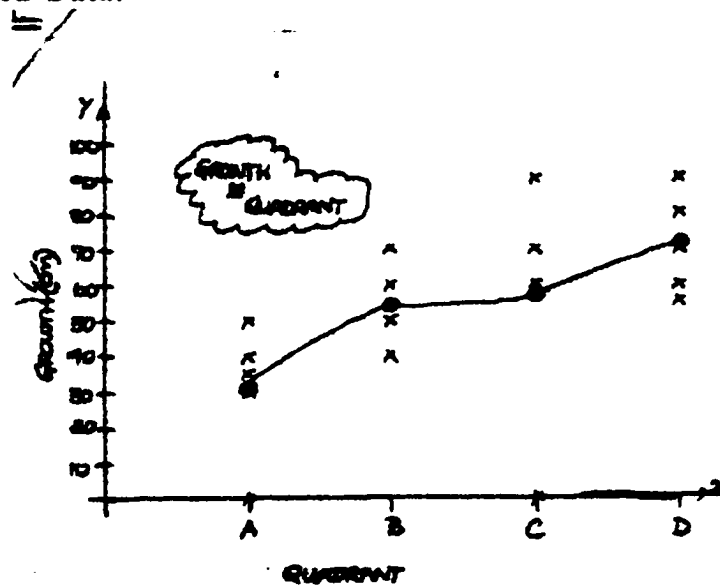


Figure 10. Scans of data & transformations from Case #3's report.

Table 1

Participants and task distribution

Population	Task		
	Lost Field Notebook	Plant Distribution Graph	Authentic Investigation
Research Scientists (<i>N</i> =15)	Think aloud (10)	Think aloud (10)	
Science teachers with B.Sc. (<i>N</i> =4)	Think aloud	Think aloud	
Preservice Elem. Science Teachers (<i>N</i> =10)	Pairwise Protocol (5 pairs)	Pairwise Protocol (5 pairs)	
Preservice Sec. Science Teachers (<i>N</i> =25)	Written (individual)		Written (11 pairs, 1 triad)

Table 2

Strategies used and comparisons made by instructors

	Strategies			Total
	Within	Between	Cross	
Ike	4	3		7
Ira	1		1	2
Ian	1		2	3
Ina	3	1		4
Total	8	4	3	16

Comparisons	
CD:	2
CE:	1
CF:	6
DE:	1
DH:	2
DEC:	1
DEH:	1
HAD:	2

Table 3

Distribution of data transformations and type of claims
by preservice secondary teachers ($N = 27$)

Representation	Relationship	
	Yes	No
Plot + best fit (outlier)	6	1
Plot only	0	4
	(.5)	(.5)
Table	0	5
Verbal	0	8
Other (cross section, ratio)	0	2

Table 4

Numerical strategies and comparisons made by preservice elementary teachers

Group	Strategies				Total	Comparisons
	Within	Between	Cross	Qual (Within)		
A	0	6	0	2	8	BH: 0 (1)
B	1	2	1	3	7	CD: 0 (2)
C	0	1	0	2	3	CE: 1 (2)
D	0	0	0	5	5	CF: 5 (1)
E	1	0	1	1	3	CH: 0 (1)
Total	2	9	2	13	26	DE: 2 (3)
						DG: 2 (1)
						DH: 3 (1)
						GH: 0 (1)

Table 5

Comparative reasoning patterns and strategies deployed with individual data points

Reasoning	Data Points Deployed	Strategy			Total
		B	W	X	
		(qual)			
high:high, low:low	D:G, D:E	3	0	0	3
			(4)		(4)
different %:	D:H, C:F, D:E:F, H:A:D	9	13	2	24
same/similar fc			(4)		(4)
same/similar %:	C:E, B:H, C:D, G:H, D:C:E	3	3	2	8
different fc			(7)		(7)
increase: decrease	D:E, C:H	0	2	1	3
decrease:increase			(0)		(0)
Total		15	18	5	38
			(15)		(15)

Table 6

Representation of the research conducted by preservice secondary science teachers with science degrees

Question	Design (operationalization)	Data Representation	Transformation	Claim
1 a. REL {host preference} {species}	{#bugs} {species}	MAP[plants] TAB([site#][species], {frequency})	SUM[#bugs], AVG[#bugs] WHISKER([AVG],[species])	REL([preference], {species})
1 b. CORR {light intensity} {distribution}	{light intensity} {location}	TAB([row#][column#], {light intensity})	MAP([intensity][isolines], {location})	+CORR([light intensity], {distribution})
2 a. CORR {height} {density}	{height} {#species/m ² }	MAP([rel. coverage], {location}) TAB([x-loc] [y-loc], {moisture} [height] {density})	SCATTER([height],[density])	+CORR([density], {height})
2 a. CORR {height} {moisture}	{height} {moisture}	.	AVG(moisture) SCATTER([height],[moisture])	-CORR([moisture], {height})
3 a. CORR {moisture} {slope}	{moisture} {x-loc} [y-loc]	MAP([moisture][plant loc] [plant height], [x- loc][y-loc]) TRANS([species][location]) TAB([x-loc][y-loc], {moisture})	BAR([density],[x-loc])	▲ noCORR([slope], {moisture}) ▲▲ CAUS([competition], {growth} {density} [distribution])
3 b. CAUS {moisture}→ {distribution} {moisture}→ {height}	♥ {moisture} {# horsetails}, x-loc ♥ {moisture} {height}	.	SCATTER([height],[moisture])	♦ REL([# horsetails] {disturbance}) ♦ -CORR([disturbance]/ {moisture}, {height})
4 a. CORR {pH} {distribution}	{pH} {rel. coverage}	MAP([rel. coverage], {location}) TAB([species], [% coverage]) TAB([location], {pH})	<none>	noCORR([pH] {distribution})
4 b. CORR {competition} {distribution}	{interface} {rel. coverage}	.	<none>	▲ competition([species1] {species2}) ▲ competition([species2] {species3})
5 a. CAUS {pH}→ {vegetation}	♥ {pH} {species}	MAP[plants] TAB([trial#][species], {pH})	AVG[pH] BAR([AVG],[species])	noREL([pH], {species})
5 b. CAUS {moisture}→ {vegetation}	♥ {moisture} {species}	TAB([trial#][species], {moisture})	AVG[moisture] BAR([AVG],[species])	▲ CAUS([moisture],[species])
6 a. CAUS {moisture}→ {growth}	♥ {moisture} {species}	MAP([rel. coverage][moisture], {location})	<none>	▲▲ -CORR([species1],[moisture]) ▲▲ -CORR([species1],[light]) ▲▲ -CORR([species1],[gradient])
6 b. CAUS {overstory}→ {mid-story}→ {growth}	♥ {species}	.	<none>	▲ <none>
7 a. CORR {moisture} {slope}	{moisture} {x-loc}[y-loc]	TAB([x-loc] [y-loc], {moisture})	▲▲ AVG[moisture] BAR([moisture],[x-loc]) BAR([moisture],[y-loc])	♦ -CORR([x-loc], {moisture})
7 b. CORR {distribution} {moisture}	{plants} {moisture}	MAP([plants], [x-loc][y- loc])	<none>	▲ noCORR ([species1], {moisture})
8. CORR {growth} [pH] {moisture}	{rel. coverage} {pH} . {moisture}	MAP[relative coverage] TAB([rel. cover], {pH}[moisture])	▲ lineG[pH],[rel. coverage] lineG[moisture],[rel. coverage]	▲ noCORR[pH], [rel. coverage] noCORR[moisture], [rel. coverage]

9 a. CAUS [slope]→ [moisture]	♥	<u>[gradient([x-loc] [moisture])]</u>	<none>	• AVG([moisture]) ▲ SCATTER([x-loc], [AVG]) • SCATTER([gradient], [Dmoisture]) • BAR([x-loc], [% gradient])	♦ -CORR([gradient] [moisture]) REL([gradient], [x-loc])
9 b. CAUS [slope]→ [coverage]	♥	<u>[x-loc] [% species1]</u>	MAP([rel coverage], [location])	▲▲ BAR([x-loc], [% species1])	♦ -CORR([gradient], [%cover])
10 a. CAUS [pH]→ [vegetation type]	♥	<u>[pH] [#species1][#species2]</u>	MAP([pH] [species1] [species2], [x-loc][y- loc])	▲ BAR([pH][#species1] [#species2], [location])	♦ Inconclusive
10 b. CAUS [pH]→ [vegetation quantity]		.	.	.	♦ Inconclusive REL([pH], [location])
11 a. CAUS [pollution]→ [productivity]	♥	<u>[distance.to.parking.lot] [#buds/blooms species1]</u>	MAP([species1], [x- loc][y-loc]) TAB([row#][column#], [#buds/blooms])	▲ AVG[#buds/blooms] LINEG([AVG], [x-loc])	♦ -CORR([smog][x-loc], [productivity])
11 b. CAUS [pollution]→ [growth]	♥	<u>[distance.to.parking.lot] [height]</u>	TAB([row#][column#], [height])	▲ AVG([height] LINEG([AVG], [x-loc])	♦ CORR([x-loc][growth])
12 a. CAUS [feature]→ [biodiversity]	♥	<u>[aspect] [rel. frequency species]</u>	MAP([plants][pH])	♦ BAR([rel. frequency], [aspect])	♦♦ REL([aspect], [species]) ♦♦ -CORR([species1], [light]) ♦♦ -CORR([species1], [moisture]) ♦♦ -CORR([species2], [heat/light]) ♦♦ -CORR([species2], [moisture])
12 b. CAUS [substrate]→ [biodiversity]	♥	<u>[location] [pH] [rel. frequency species]</u>	.	<none>	♦ <none>

Key:

CORR - correlational statement/claim made (i.e., one variables measure covarys with another measure)

REL - relational claim made (i.e., with categorical variables)

CAUS - causal statement made (i.e., one variable causes another to change)

TAB - data represented in a table

MAP - data represented in a map/drawing

TRANS - landscape viewed in a side profile

BAR([y][x]) - Bar graph used

SCATTER([y][x]) - Scatterplot graph used

LINEG([y][x]) - Line graph used

WHISKER([AVG][species]) - categorical graph

plotting averages w/ range in each category used

AVG[variable] - average given for a variable

single underline - conceptual problem in

operationalization of variable

double underline - problem in implementation of

operationalization of variable (e.g., replication, sampling)

♥ - problem of relation of variable1 to variable2

• - transformation not related to original question

▲ - inappropriately used graph (e.g., bar instead of scatterplot)

♦ - claim not related to original question

♣ - claim is not conceptually related to the data which was collected and presented

Table 7: Claims made in the reports of the three case studies

Claims in Reports	
Case Study 1	1. We found that the area with the highest horsetail density had the horsetails with the tallest height. This could be that the areas with the highest density had the most favorable conditions such as nutrients, shade, and light, which allowed them to grow taller. 2. We found that the areas with the least moisture content had the horsetails with the tallest height. This could be that the taller horsetails have absorbed more water (nutrients) thus reducing the moisture content of the soil. 3. Additional questions that might require further investigation might include how competition with other plant species affects the height and density of horsetails; how soil type affects soil moisture; and why the density of horsetails decreased with proximity to the road.
Case Study 2	1. Moisture at the top of the slope on a sunny day is greater than in the middle or bottom. This is probably due to moisture (e.g., rainfall) hitting the soil at the top more often than elsewhere because of how various plants on the slope prevent moisture from accessing the soil, i.e., there are fewer plants at the top of the slope. Gradually, rainwater at the top would run down the hill because of gravity. 2. Further tests could help determine the effects of plant type versus position on slope. We also might learn more by taking moisture readings in the soil during or after various degrees of rainfall. Presumably, different plant types utilize different amounts of moisture so we could test soil moisture around various types. 3. Pattern of fern placement on the slope is not related to moisture content of the soil. 4. Further tests could indicate whether fern placement pattern is due to competition from other plants, symbiotic relations with other plants, availability of sun versus shade, pH of soil, wind resulting in fertilization and distribution of spores, animal movement resulting in distribution of spores, animal and human traffic effecting survival of plants.
Case Study 3	1. It is possible that smog decreases both productivity and growth of lupines. 2. Growth shows a more consistent correlation with distance from the parking lot (used as a measure of concentration) compared with the productivity. 3. The fact that a street exists on the opposite side of the parking lot indicates why a decrease in productivity occurs in quadrants after B. 4. One parameter that was not controlled in this investigation was the influence of smog.

Chapter 4:

Graph interpretation practices of science and education majors

Graph interpretation practices of science and education majors

Abstract

Studies of scientists show that graphing is central to the conduct and communication of science research. Thus, developing competency in using and reading graphs is an important aspect of learning science and about science. Current reform documents in North America propose that: (i) public school science classrooms have students engage in “hands-on” inquiry practices in which they summarize investigative activities using graphs, and (ii) education students take science courses instructed by science department faculty members. Past research has demonstrated that preservice secondary teachers did not on their own default to the graphical summarizing/interpretive practices of scientists. We examined the graphical analysis practices of pre-service elementary teachers and science graduates on a number of graphing tasks. We conclude that there were few differences between those two groups in their interpretations and thus that taking the lecture-oriented science courses common to science programs would not necessarily improve education students’ abilities at summarizing data or interpreting graphs. We make suggestions regarding the type of course which should address both the content and process issues of their science backgrounds.

Sociological research into scientific activity reports that graphs are central to the entire conduct of science. This research includes: ethnographies of scientists conducting their everyday research (e.g., Woolgar, 1990), historical analyses of the construction of scientific claims (Garfinkel, Lynch, Livingston, 1981), and interpretive analysis of the writings of scientists (Bastide, 1990). Graphs have this important role because they efficiently summarize trends over time or covarying relations between two (or more) variables. Further, they can compellingly depict theoretical models of relations between variables providing a conceptual foundation for new research.

Because graphs are so central to the practice of science, our research agenda is concerned with the development of scientific practices involving their use—including the conduct and summarization of research. Thus, we conduct long-term studies of graphing in school settings (elementary to high school), university science courses, and professional science (postdoctoral, research work). We also investigate to what degree future teachers use and interpret graphs in the way specified by recent reform documents (AAAS, 1993; NCTM, 1989; NRC, 1994).

These reform documents have called for “authentic” practices in mathematics and science education which would allow students to engage in these subjects in ways that resemble the everyday activities of practitioners in these fields (Table 1). These suggested curriculum reforms for mathematics easily integrate into science curriculum reforms with a focus on developing competency at data collection, analysis, and presentation. In fact, the integration of mathematics and science activities may be essential for developing in children the thick layer of experiential knowledge that underlies much of scientists’ understandings (Roth, 1996; Roth & Bowen, in press; Roth, Masciotra, & Bowen, 1998). Further, the integration of rich experience with physical phenomena and subsequent data transformation/analysis appears to lead to robust mathematical and scientific understandings of phenomena (Greeno, 1988; Roth & McGinn, 1998).

[Insert Table 1 about here]

Previously we reported that pre-service teachers did not default to scientific practices in either designing and interpreting field research projects (Bowen & Roth, 1998a) or when interpreting a “realistic” ecology word problem (Roth, McGinn, & Bowen, 1998). This may be interpreted as a lack of familiarity with scientific practices. Universities have dealt with the lack of familiarity with scientific practices in pre-service elementary teachers by increasing the number of science courses they must take—which is premised on the assumption that more science instruction develops greater scientific competency. In addition, some funding agencies now require that science faculty members be involved in the preparation and planning of science courses for education students. However, with regards to graphing the efficacy of this solution remains unexamined. One study of a science faculty member teaching an education course, “an exemplar of what the National Science Foundation administrators have in mind when they require arts and sciences faculty to teach such courses as a requisite for funding” (Roth & Tobin, 1996, p. 138), reported that his lectures did not help students become proficient at using graphs. In this article we extend our previous research by asking, ‘What is the nature of graph interpretations by teachers who have science degrees and pre-service elementary teachers who have taken few, if any, university level science courses?’

Study Design

Our approach for studying science in schools, university, and professional practice is informed by the emergence of anthropological, ethnomethodological, and sociological studies of scientists at work (Latour & Woolgar, 1986; Lynch, 1985; Traweek, 1988) and by the recent conceptualization of graphing (and science in general) as social practice (Roth & McGinn, 1998). Influenced by this work, we do not consider scientists to be a special breed of people. Rather, this work and our own ethnographic work among scientists shows that science is characterized by sets of mundane practices shared by the members of

specific communities. From this perspective, knowledge is not something residing exclusively “in the heads” of people but is constituted to a large extent by the ways people (scientists) go about their daily business, how they justify what they do, the stories they tell, and so on. Given this, to investigate how an increased science background might mediate the interpretation of graphs, we examined the graph interpretation practices of students in the fifth year of an elementary education program contrasted with those of science graduates. These were compared with interpretations of the inscriptions collated from interviews with individuals who had experience conducting, summarizing, and writing about science research.

Participants

The main participants in this study represent two distinct groups. One group of five pairs of “pre-service elementary teachers” in the fifth of a five year university program in Western Canada. They had a minimum of three science and two science methods courses all taught by faculty of education instructors. The second group, five “science graduates,” had obtained B.Sc. degrees but had not conducted independent research projects (although they had all worked as assistants on the projects of professional researchers). For comparative purposes, interviews were conducted with sixteen professional researchers (from the public and private sector) which allowed the construction of “model” interpretations of the inscriptions. The analysis was also informed by ten students in a science program (taking a second-year course in ecology) who provided videotaped and written interpretations.

Data Sources

To understand the interpretive practices of the pre-service teachers and the science graduates we examined their interpretations of three inscriptions (Figure 1). The first inscription, a population growth graph (Figure 1a; PG), was drawn from a problem set presented in the seminar of a second year ecology course. The second inscription, a plant

distribution graph (Figure 1b; PD), was drawn from a second-year ecology course lecture (Bowen & Roth, 1998b). The third inscription, the “Lost Field Notebook” problem (Figure 1c; LFN), was a data map of a field drawn from the work of grade 8 students conducting field research (Roth & Bowen, 1995). Participants were videotaped as they provided interpretations of these inscriptions. In total, 21 hours of videotape was analyzed: elementary education students—6 hours; science graduates—4 hours; “experienced” researchers—8 hours; ecology course students—3 hours.

[Insert Figure 1 about here]

Data Analysis

Transcripts of interviews were made in an on-going fashion as the study progressed allowing for preliminary analysis and the collection of relevant additional data. All records were subjected to an interpretive text analysis grounded in semiotics (Bastide, 1990) and hermeneutics (Ricoeur, 1991) of scientific texts. We independently conducted interpretive analysis of the data to develop tentative assertions—focusing on participants’ ongoing concerns, interpretive resources, and breakdowns (areas where they encountered difficulty). We then re-joined and collectively examined our independently derived assertions, compared them to original sources, and discussed the validity of each claim. Through repeated cycles of group discussion and independent analysis we identified dis/confirming evidence for our tentative assertions leading to further refinements of our claims to ultimately establish consensual claims. This sharing and critiquing assisted in the process of progressive subjectivity (Guba & Lincoln, 1989) and helped guard against developing nonviable interpretations. The understandings reported here emerged from these iterations. Each author also brought different interpretive perspectives to the data sources—in large part because of their different uses within our former disciplines. GMB, a former field biologist, and WMR, a former research physicist, take different views on the interpretation of inscriptions. We used our different frames of reference reflexively to

provide a deeper interpretation of the data and to more effectively critique the independent assertions we presented in meetings.

Model Interpretations of Inscriptions

We consider graphs (and their captions) as multi-modal texts which can be parsed into signs (Roth, Masciotra, & Bowen, 1998). However, what these collective signs refer to in the world depends on the context of the graph and the experiences of the viewer. “Model” interpretations were constructed to provide a foundation against which the interpretations of our participants could be compared and to provide the reader sufficient context for understanding the interpretations we offer of our participants’ interpretive efforts. The model interpretations are composites derived from the interpretations of sixteen researchers, professors, and others with research experience.

To provide the reader with an understanding of how these models were derived, we detail excerpts of our construction of the model for the Population Growth graph (PG; Figure 1a) referring to the original source interviews with an experienced researcher. This excerpt comes from an interview with a physics researcher and typifies comments made by experienced researchers regarding the intersection points in the graph and the implications of the juxtaposition of the birth and death rates on changes in population size:

There are two points where death rate and birth rate are the same. So there is no change in the population at these points. So, a little to the left of the left point, the death rate is larger than the birth rate, so the population will disappear; a little to the right of the point, and the population will grow. An unstable equilibrium point. Near the other point, the population increases on the left, but decreases on the right side. A stable equilibrium point. This is evident.

This excerpt illustrates that the concept of “equilibrium” is related to intersection points on the graph and these are an important feature to consider when interpreting this graph scientifically. Most of the experienced researchers made reference to the intersections and

the implications of the juxtaposition of the birth and death rates either explicitly or implicitly.

Another important aspect of interpreting a graph and relating it to “biologically realistic” situations involved recognizing where variation would exist in a natural population (which would normally appear as data scatter) but which is only implicit in the graph (in the current cases because only the trend lines and not raw data or averages were plotted). A theoretical ecologist discussed the “variation” present in a natural population but not visible in the graph, “[There is] error around these relationships that I don’t need to be aware of. At least, I assume it’s there.” In stating this he noted the variation implicit in the model which mediated its application. Another ecologist, a field researcher, commented that he considered the trend lines in the graph to be misrepresentative (to students) because they were drawn as “thin” and not “fat.” To him, the fat lines would indicate variation in the system whose exclusion meant a misleading representation of stable and unstable intersection points which for any population, if such points did exist, would more likely be found in a wide range rather than at a single point. From this we concluded that consideration of variation in the raw data/actual population is an important aspect of effectively interpreting the graph.

By conducting a similar analysis of all of the transcripts of experienced field researchers we constructed the model interpretations containing features generally found in their interpretations (Table 2). In general, these individuals made frequent reference to their own research work and related the variables and the relationships depicted in each inscription to examples in the “outside” world iteratively cycling back and forth between the features in the graph and associated outside referents. In the following sections we contrast the interpretive activities of the preservice elementary teachers and the science graduates with each other and compare their conclusions with the model interpretations and how they were enacted.

[Insert Table 2 about here]

Findings

This study was designed to better understand the graph interpretation practices of university students who, qualitatively and quantitatively, had different science course backgrounds. In so doing, this study inscribes itself within our overall effort to better understand graphing practices from middle school to everyday scientific and non-scientific practice. The results presented here therefore figure against the background of our entire research program.

In all three interpretation tasks, our analysis highlights two major features which distinguish the participants in the present study from practicing scientists. First, participants were most concerned with the representations in themselves rather than with any external referents—that is, the phenomena to which representations are an index. This contrasts with the readings provided by the scientists—who had a wealth of personal experience with graphs, the scientific phenomena they refer to, and translations between the two—who made constant comparisons to external examples.

Secondly, participants did not default to the practices or conventions engaged in by experienced interpreters and struggled with how to proceed. Scientists had accumulated conventional knowledge and embodied default practices—things one normally does and says about representations. Despite their university science courses the science graduates, like the pre-service elementary teachers, did not enact such conventional and embodied knowledge.

We refer to interpretations which only reference information “inside” of the graph structure itself and which rarely or never explicitly draw comparisons to information external to the graph as being “referentially isolated.” Two general types of references to information “outside” of the graph can be made: (i) to the standard mathematical practices typically engaged in by scientists in the conduct of science and interpreting graphs, and (ii)

to biological situations/examples which are said to be “represented” by the graph. Both cases represent the opposite of “referential isolation” because in each case the participants could be explicitly using information from “outside” of the representations structure or textual information. Typically, the interpretations made by both the pre-service elementary teachers and the science graduates were referentially isolated because they did not draw on (i) or (ii). These differences in interpretive practices, compared to more experienced researchers, affected the participants’ efforts in making the representations ‘speak’ in the way they would to more experienced readers so that ultimately their understandings of the inscriptions differed from those of the experienced researchers.

To show that these claims hold across the context within which the various representations are situated, we present evidence from the interpretation efforts of pre-service elementary teachers and science graduates on two graphing and one data transformation tasks. This evidence is presented for each of the three tasks in two sections. The first section (“Referential Isolation”) gives examples of interpretive activities from the pre-service teacher and science graduate groups which were common amongst the experienced researchers but uncommon in these two groups. The second section (“Ambiguities of Information”) highlights difficulties that commonly arose in their interpretations at a similar point on all three tasks. Here, we provide examples of the pre-service teachers and science graduates as they experience breakdown in their interpretations while trying to make sense of the axis labels/variables used in each representation. This breakdown, which frequently occurred, resulted from the lack of external referents on which most participants could draw. “Negative cases” are provided of those pre-service teachers and science graduates who drew on external references, did not experience this breakdown, and progressed farther on the trajectory towards providing the model interpretations than did those whose interpretations were referentially isolated.

Population Growth Graph Interpretation

An interpretation of this graph by experienced researchers usually included considerable discussion of both mathematical and experiential referents as they made sense of it. Their discussion of the graph made frequent reference to external referents (e.g., some animal population, such as fish) which were used to stabilize their understanding of the relationship shown in the graph as they iteratively referred back and forth to “outside” examples and elements of the graph. Central to their analyses was first a recognition that birth rates equaled death rates at the intersections and secondly that the leftmost intersection represented an unstable equilibrium and the rightmost a “stable” equilibrium around which, in real populations, there would be oscillations. Most mentioned (or otherwise indicated) that the graph depicts a model instead of empirical data (which is central to its interpretation) because of the lack of data scatter (plots of raw data/averages) and/or their familiarity with natural populations of animals (Table 2A).

The interpretations of this inscription by the pre-service elementary teachers and science graduates differed in several ways from those provided by experienced researchers but differed little between those two groups—they infrequently drew on examples “outside” of the graph (e.g., discussing an animal population, such as cod, that this graph might refer to). This referential isolation resulted in difficulties arising in their interpretation such as being able to “make sense” of the variables which constituted the axis labels, recognizing that populations might have a theoretical equilibria, and making a distinction between the graph being a model versus it representing empirical data.

Referential Isolation

There were many differences, and few similarities, between the interpretations of the pre-service elementary teachers and the science graduates compared to those of the experienced researchers. Only rarely did the pre-service teachers or science graduates link features of the graph to features in the world, engage in interactive cycling back and forth

between features of the graph and external examples, and draw on specific examples of animal or plant populations. However, it is difficult to demonstrate that their interpretations were referentially isolated because it is the lack of outside references which is the observation of note. We will address this in two ways by either highlighting how members of these groups proceeded with their interpretations differently from experienced researchers or by offering examples of negative cases which demonstrate infrequent similarities with experienced researchers.

One approach used by pre-service teachers when interpreting the graph was an attempt to construct an “outside” reference when they did not have any related experiences to draw on. This was done by speculatively relating aspects of the graph to human populations, an organism whose biology they did have experience with, and their possible reaction to the scenario portrayed in the graph. In another study using this graph undergraduate science students with little or no field experiences were observed “constructing” examples to help their understanding—usually scenarios of the potential responses of a human population (Bowen, Roth, & McGin, in press). In neither of these did the “constructed” examples allow the participants to draw conclusions about the graph which paralleled those of experienced researchers. The science graduates in this study engaged in similar practices by either discussing examples that were completely referentially isolated (i.e., referring to generic “organisms”) or constructing examples about populations “outside,” but about which they knew little of the specifics. As an example of the latter, one of the science graduates constructed an example relating patterns in this graph to a population of brambles:

I throw in the brambles to start with and that still seems to make sense to me.

Brambles and the distance that the pollen can travel. I’m sticking with the brambles because then you don’t have to worry about mobility and regrouping as such. So, if N is in fact density, you don’t have to worry about a dynamic density. That would

make sense because if their pollen can only travel five meters, if their density is down here, it's very low density. Some of the plants may be within 5 meters of each other, so their birth rate is still there, they pollinate and then the seeds fall and a new plant comes up. [Ira]

In the course of this analysis, Ira attempted to make sense of the component parts of the graph through a constructed example, for which he relied on his (self-described) brief experience with brambles out-of-doors, bringing each of the terms used on the graph into some perspective through relating them to brambles. The scenario constructed about brambles was not unlike scenarios of possible human population responses to similar ecological situations (i.e., low density, trouble finding mates, etc.) proffered by other participants but which did not lead to the conclusions drawn by experienced researchers.

There are consequences for not linking the graph to outside referents. A common practice in science, and one often important in interpretation, is distinguishing between theoretical models and representations of empirical data. Unlike the experienced researchers whose discourse about the graph suggested that they recognized the population growth graph was a theoretical model and did not represent empirical data, none of the pre-service elementary teachers or science graduates gave any indication that they were making such a distinction—which is a consequence of not linking it to outside references. Making the distinction is necessary because if the graph is viewed as representing empirical data then interpretation becomes confounded to the left of the first intersection point where death rate is greater than birth rate then the population declining to zero. For interpreters two problems arise: (i) how could the data have been collected without driving the population to extinction, and (ii) how could the population have grown in the first place to become sustainable. In another study, second year ecology students experienced breakdown in their interpretations because of these problems (Bowen, Roth, & McGinn, in press).

In this current study there was little evidence that most interpreters made a distinction between the graph representing a model or data. However, one pair of pre-service elementary teachers explicitly dealt with the graph as representing empirical data and did not experience the contradictions of other interpretants because they developed a scenario for its use in the “outside” that allowed internal consistency in their interpretation. In so doing, their interpretation of the graph was the only one which paralleled that of the experienced researchers (they therefore constitute a “negative case” (Guba & Lincoln, 1989)). These pre-service teachers developed an elegant rationale for the graphs use, avoided interpretive breakdown, and were able to proceed further along the trajectory of answering the question than any other group in the study. Much like the ecology students, they were at first confused at how the population could have grown from low numbers in the first place, but then resolved this conflict by positing that the graph could represent the introduction of a species to a new area (a common scientific practice):

So if you introduced species into an area and say you only had, you didn't have enough to get pass this [left] point, you're not successful. [Erna: Exactly] And when they get past this [left] point, they should go up to here (right intersection) and then maintain that population. [Ed]

This proposal allowed Ed and Erna to resolve their earlier difficulty with the graph's derivation, avoid the conflict encountered by the ecology students, and thereby develop an interpretation which was internally consistent.

Ultimately, Ed and Erna proceeded further in their interpretation of the graph than did any of the other pre-service teachers or science graduates and they did so by relating the graph to an “outside” referent and standard scientific practice—introducing a species to a new area. As did the experienced researchers, they recognized that the left intersection was an unstable equilibrium to the left of which the population would drop to extinction and that the right intersection represented a stable equilibrium towards which the population would

tend (once past the size indicated by the left intersection). In addition to their use of external referents and consideration of the common scientific practice of “introducing” a species, they also drew on substantially more external referents than all of the other groups combined including natural populations they had heard about (bears on Vancouver Island, birth control in China, the baby boom, and teenage mothers) and those they had seen interact (rabbits on campus). Only one other group made reference to a specific animal population (black-tailed deer) and their graph interpretation was halted because they did not clearly distinguish between rate of change and number of organisms in the population (discussed in the next section).

Another conventional science practice when interpreting graphs is to focus on intersecting lines and peaks or valleys. The pre-service elementary teachers and science graduates in this study had difficulty determining whether an intersection of two lines was significant and how it should be interpreted. Although three of five of the science graduates concluded that at the intersection points death rate equaled birth rate, only two suggested that the left intersection point represented an unstable equilibrium and the right intersection represented a stable equilibrium. Among pre-service elementary teachers, two groups clearly identified that the intersection points corresponded with death rate equaling birth rate with the implication that there was no population growth. Identifying this was a key component of interpreting the graph and addressing the question. Two groups of the pre-service teachers, and one of the science graduates, discussed population oscillations as being a normal occurrence in animal populations because of disease, etceteras. Almost all experienced researchers focused on the intersection points and discussed the type of equilibria around each of these intersection points—although since this is what the question said to do this is unsurprising. Many of the pre-service elementary teachers and science graduates seemed not to actually reach this point in their analysis of the graph experiencing

breakdown earlier when trying to determine what would help them understand what might affect the individual variables and exactly what those individual variables were.

Ambiguities of Information

Graphs and their captions do not provide unambiguous information (Bastide , 1990). This led in our study to an examination of where graph interpreters experienced breakdown in interpreting graph axis labels or captions. In the Population Graph the variables (constituting the axis labels) were unclear in origin or meaning causing interpretive problems for members of both groups—possibly because they did not or could not relate them to outside referents or canonical practices. Three of the groups of pre-service elementary teachers spent time trying to define the axis label “N” and eventually decided it represented population size. Although Ira and one of the other science program graduates decided that “N” represented population density, another science graduate, Ian, was very uncertain about what “N” represented and this greatly contributed to his difficulty interpreting the graph: “N is the number of, number of organisms? or, actually hold on a sec, is N, I guess because it’s two, line graphs overlaid, is N for this one the birth rate and N for this one the death rate?” In the end, Ian left the definition of “N” unspecified and focused on the implications of the intersections. However, his uncertainty about what “N” specified ultimately resulted in ceasing his interpretation before he had answered the question to his satisfaction. Our interviews with experienced researchers revealed that they interpreted “N” as representing either density or population size, typical scientific conventions for “N” (both in biology and physics) and spent little or no time considering how the information was collected. Unlike our experienced researchers who “knew” what the labels represented, for our pre-service teachers and science graduates, consideration of how the data was collected helped stabilize what they thought the label represented.

One group of pre-service elementary teachers did not engage in a discussion of what “N” represented but experienced difficulty making sense of the variable represented on the

ordinate axis. They did not successfully interpret the graph because they conflated the axis term “rate” with “number” and treated the ordinate axis as representing population size thus confounding their interpretation. In total, three groups of pre-service elementary teachers did not clearly distinguish between “rate” (as in birth and death rate) and change in number of organisms. Near the end of their interpretive efforts, the pre-service teachers still often confounded population change rate and population number:

The only reason I can see for the death rate increasing is if the population is also increasing because if you have a constant increase in population, the death rate is not gonna stay the same because you have more people you have to have more death. [Eli]

Interpreting rate as change in absolute population size contributed substantially to their conclusion that they needed “more information” before they could provide an answer for the graphs’ question.

In the end, only one of the groups of pre-service elementary teachers and none of the science graduates provided an interpretation that resembled those of the experienced field researchers. In general, they: did not draw on examples external to the graph, neglected to discuss the intersection points and population changes around them, insufficiently discussed the implications for conservation of a species, and did not engage in conventional distinctions. In addition, there were often elements of their conclusions which were incorrect. For instance, two the science graduates and two groups of the pre-service elementary teachers concluded (incorrectly) that if the population moved to the right of the second intersection point it would then become extinct.

Plant Distribution Graph Interpretation

The interpretation of this graph by the pre-service elementary teachers and science graduates proceeded further along the trajectory towards the “model” interpretations than for the Population Growth graph. However, compared to experienced researchers there

were still differences in the use of external references, extended narratives, difficulties interpreting the axis labels, and comparisons made to the biology of the organism.

Referential Isolation

As with the Population Growth graph, the interpretations offered by the science graduates and pre-service elementary teachers for the Plant Distribution graph (Figure 1b) stand in contrast to those provided by experienced field researchers because of their focus on the graph itself and their infrequent reference to examples outside of the graph. Experienced field researchers discussed the graph in relation to its implications for the organisms in the field and usually made frequent references to examples drawn from the “outside” world. The pre-service elementary teachers and the science graduates generally provided “literal” readings of the graph which only infrequently extended to discussing the implications of the graph in relation to the biology of the organisms whose range was depicted in the graph. This suggests that they lacked situations or examples to draw on that could have helped them elaborate their understanding of the graph. During their interpretations the experienced researchers linked this graph to their personal experiences but only rarely did any of the pre-service elementary teachers or the science graduates do so. To most of these participants, these were literal, referentially isolated readings (“all this does is tell us where these three points are”).

While making sense of the plant distribution graph, its components, and the caption, the experienced researchers usually gave detailed narratives about their ‘out-of-doors’ experiences which they related to the graph and its component parts. Lengthy narratives were used only once by a pair of pre-service elementary teachers and one of the science graduates to help develop their reading of this graph. In the following 2-minute excerpt, two of the pre-service elementary teachers relate the graph to their experiences:

Ella: They’d have to be sort of a versatile plant, I know from when I was in the desert because it gets very cool at night and then extremely hot in the day

Eli: But is it moisture they take in the desert or is it just cold?

Ella: We weren't in Texas but, I was down in Joshua Tree, down in Southern California

Eli: Because this is a tip off as well as the elevation thing going on, right, elevation at 2000 I think there are mountains somewhere or way above sea level, this is 2 kilometers up. I don't think it's that high though, the reference is the ocean level. I don't understand how a plant can be that versatile at high altitude

Here Ella and Eli discuss several aspects of their out-of-doors experiences in relation to the information in the graph and use those experiences to help them make sense of the graph. None of the other pre-service elementary teachers used lengthy narratives such as this while making sense of the graph. Also, only one science graduate used an extended narrative when discussing the graph. In that narrative he related an experience hiking up Mount Kenya in Africa to make sense of the relation, depicted in the graph, between elevation and moisture. By drawing on these experiences, associated with a change in climate and plant populations, he reified his understanding of the correlation elevation and moisture/temperature implied in the text of the graph thus allowing him to move forward to a discussion of the juxtaposition of the trend lines themselves.

In general, longer narratives, such as the use of "outside" experiences to help interpretants make sense of the graph represent "negative cases" of referential isolation being uncommon in both groups of participants. Comments relating the graph to personal experience were usually only a single sentence in length (e.g., "Thinking about skiing, it could be the opposite too. . ."). Experienced researchers, however, usually offered rich narratives connecting elements of the graph to "outside" experiences. For both of the narratives offered by participants in this study, we found it interesting that neither related experiences which the interpretanting individual had garnered through at least sixteen years of schooling. This suggests that their schooling activities in science had infrequently

connected academic matters to the “outside” world and also the converse; that participants did not often connect their everyday “outside” experiences to school (or school-type) experiences (such as interpreting graphs).

Interpretation of the plant distribution graph was also referentially isolated in the sense that the biology of the organisms warranted little comment. Overall, there was infrequent mention about the biological implications or causes of the patterns depicted in the graph—which lies in contrast to the interpretations of the same graph by experienced researchers (Table 2b). Most participants made brief comments about the peaks corresponding with where that plant ‘best survived’, but the difficulty interpretants had with the axis label “Relative Importance” hindered a discussion of survival and its relation to the peaks and valleys in greater detail.

To demonstrate why it was important to draw on outside referents to make sense of contradictions between the caption and the graph we provide the following excerpt (representing a “negative case” because no other interpreters used outside referents to resolve this contradiction). This excerpt shows one pair of pre-service teachers drawing on their understanding of scientific graphing practices when interpreting the graph to make sense of and resolve a contradiction between the caption text and the trend lines. Their elaborate analyses related the juxtaposition of the lines, the anomalies in the caption, and biological aspects of survival and concluded that the apparent “relative importance” of the C3 plants was driven in part by that of the CAM plants:

And it looks like that they all survive a little bit in each environment but this one is kind of anomaly, C3, when it gets really hot and dry, it starts to peak and then when it gets really cold and wet . . . then [C3] also start peaking again here but maybe that’s just the falling of [CAM], so these ones happen to, like they survive here. . . they fill in just because [CAM] can’t survive.

See with [C4], what looks like to me is that as [CAMs] drop off, [C3, C4] just sort of fill in the gap 'cause [CAM] can't survive. [Ed]

They concluded that the trend lines for C3 and C4 plants went upwards on the graph because the CAM plants could not survive in the hotter and drier climates and so, relatively, the C3 and C4 plants became more important. Their analysis, which indicated that they had resolved their difficulty with the term "Relative Importance," suggests that these pre-service teachers had some understanding of both biological influences on plant survival and also how misleading artifacts can arise from the measuring and graphing of variables.

In general, interpretations were referentially isolated lacking both extended or short comments which related the graph to their experiences, canonical mathematical practices, or to the biology of the organisms. The referential isolation of interpretations by the pre-service teachers and the science graduates, and the little progress they made on the trajectory towards the model interpretations, highlight how important the use of external references are to "making sense" of graphs. In contrast, the interpretations given by experienced researchers provided more internally consistent interpretations of the plant distribution graph because they were able to offer extended narratives which "connected" the graph to other knowledge and their "outside" world experiences with organisms.

Ambiguities of Information

The breakdown experienced when trying to interpret axis labels is a good example of the effect of referential isolation. As with the interpretations of the Population Growth graph, elements of the construction of this graph, such as the participants understanding of the axes labels, interfered with the graph interpretation. For some of those interpreting the Plant Distribution graph the ambiguity of the term "Relative Importance" was more problematic than for others. For one of the science graduates and one pair of the pre-service elementary students the ambiguous nature of "relative importance" interfered little with their interpretation and they spent little time discussing its meaning. In this their interpretations

were similar to those offered by the experienced researchers who often made mention of the ambiguity of the term “relative importance” but whose interpretation proceeded without breakdown despite this. Other pre-service elementary teachers and science graduates experienced various degrees of breakdown in their interpretation of the graph because they did not know how to interpret the term “relative importance” and did/could not relate it to any “outside” referents. One pair of pre-service elementary teachers and one of the science graduates tried to make sense of this term by determining mathematically if the ordinate values summed to the same value at different elevations. They were frustrated to find that the calculated values did not support their hypothesis that “relative importance” was a transformation of percentage. The inability of one of the science graduates to resolve what “Relative Importance” made it impossible for him to make sense of the entire graph.

An inconsistency between a statement in the caption and a trend visible on the graph also caused some confusion. Some of the pre-service elementary teachers and science graduates noted the anomalous relationship between the graph caption and the trend line—Line C3 was noted to be unusual because of its “dip”; this dip appeared to contradict the caption according to which C3 plants predominated at the cooler, least dry end of the gradient but not where it was hottest and driest. Although this anomaly hindered interpretations less than did the term “Relative Importance,” the inconsistency was noted by many of them. Only one group (the one with “Ed” described above) developed a rationale for this contradiction.

Lost Field Notebook Problem Interpretation

This inscription represents the most difficult of the three tasks because a canonical response involves both transforming the data into a graph and then interpreting the trend. When interpreting this inscription the following solution sequence was typical for experienced researchers—plot the data, check for outliers, and conduct a regression analysis. Typically, the subsequent conversation for research biologists involved physical

features which might influence the relationship: streams, shading, hills, and other factors. Plotting a trend line of the plotted points shows a weak relationship between light intensity and bramble density ($r = .46$), which is considerably stronger ($r = .77$) if area “C” is considered an outlier. Compared to interpretations by experienced researchers, the interpretations by pre-service elementary teachers and science graduates made little progress towards the “model” answer—often their answers were essentially qualitative and the relationship “eyeballed” by comparing pairs of numbers. This breakdown seemed to occur, in part, because of ambiguity in how (and why) the data was collected.

Referential Isolation

Unlike the experienced researchers, for the most part neither the pre-service elementary teachers nor the science graduates made any comparisons “outside” of the graph—to either canonical scientific approaches to such a problem or to any out-of-doors references. Such a response is interesting because everyone has experience being out-of-doors in varying light conditions. Yet, there were few references to these experiences, or to the graph-making experiences related to pairs of numbers which are learned in school from senior elementary upwards—the participants compared pairs of numbers without constructing a scatterplot graph to help them look for patterns. When asked to interpret the Lost Field Notebook problem, they inspected the data and, without transforming or graphing the data, made the claim that no relationship existed between light intensity and bramble density.

. . . it seems, you know, the higher [D], the higher light higher coverage,
but then when you look at like between 200 [D] and [E], between 1200 [D]
and 1500 [E] it looks like that but then when you look at this one [H], well,
that’s not very high, so why not? [Ina]

This excerpt, typical of interpretations by members of both groups, demonstrates that the interpreter is referentially “stuck” working with numbers in the graph alone and not drawing any references to features outside of the graph. For instance, if they had drawn on

canonical mathematical practices when interpreting the graph then they would have sketched a scatterplot of the data, drawn a trend line, and would have noted a weak correlation. By not engaging in these practices their interpretation is referentially isolated from canonical mathematical practices. Most science graduates and pre-service teachers started their interpretation using pairwise interpretations of data points, such as in the example, to investigate whether a relationship existed but none drew a scatterplot. Although each compared several pairs of numbers, when asked what claim they would make and how they would support it most participants cited only one pair of numbers that contradicted the relationship between light intensity and bramble density—another practice not representative of canonical mathematical practices.

Ambiguities of Information

If the pre-service elementary teachers and science graduates had drawn scatterplots then “light intensity” and “bramble density” would have been axis labels. As with the previous two graph interpretation problems, ambiguity around the individual variables (i.e., potential axes) interfered with interpretation of the problem. When making sense of the Lost Field Notebook problem members of both groups spent time engaging in: (i) discussing what factors may have influenced variations in the individual variables, and/or (ii) discussing how each of the variables might have been measured. The factors discussed may have influenced the relationship ranged from the specific (i.e., soil type) to the general (i.e., terrain). Although this represented some effort at drawing on outside examples, inability to relate these to their own experiences meant that they were unable to resolve which of their referents were relevant and thus they experienced breakdown in their interpretations. Experienced researchers did not spend any time discussing what factors might have affected the individual variables until after they had determined if there was a relationship. In discussing the individual variables the pre-service teachers and science program graduates also demonstrated that they were using definitions of terms which were different

from those used in science. For instance, the definition of “density” used by some groups was not that normally used in this type of research (number of plants per area) but instead dealt with how “high and bushy” the brambles were. These alternate definitions of terms might have contributed to the difficulty experienced by the groups in making sense of the data.

Unlike the interpretations by experienced researchers, and despite their efforts at understanding the individual variables, none of the pre-service elementary teachers or science graduates plotted the data on paper, identified outliers, or suggested regression analysis—nor did their discourse give any indication that they were “mentally plotting” the relationship (as two of our experienced researchers said they did) or use any other form of tabular comparison. The conclusion of all participants was that there was no relationship between the variables of light intensity and bramble density—similar to claims made by others when they did not transform the data in this problem (Roth, McGinn, & Bowen, 1998).

Discussion

In this study we have documented the graph interpretation practices of pre-service elementary teachers and science graduates (who were not in a teacher education program). Few substantive differences existed between the interpretive practices enacted by the pre-service elementary teachers and those engaged in by the science graduates. In general, as their interpretations unfolded our participants made little progress along the trajectory towards the “model” interpretations. In a previous study (Bowen, Roth, & McGinn, in press) we reported that students in a second year ecology course did not draw on external referents in their sense making when working on a graphical problem (the population growth problem). In that study and the present one, the participants generally did not engage in the interpretive practices which experienced researchers (who had conducted, summarized, and constructed rhetorical arguments from their data in long-term studies)

used automatically. This suggests they had either a lack of experience relating graphs to external referents or few external referents to draw on. Also lacking was the conventional ‘wisdom’ which has scientists plot data in certain situations (and not others), knowledge of what scientific terms (such as “N” or “rate”) might mean, and knowledge of data collection procedures.

Scatterplots, such as that of the Population Growth graph, are generally considered to be an effective tool for illustrating the covariation between two (or more) measured variables (although that view certainly falls into question with this study). To effectively interpret the graph with the intent of the its author(s) an interpreter would supposedly need to focus on the relationship of covariation and not just on the variations within individual variables.

However, this study appears to suggest that interpreters need to understand the graph at the level of the individual variables (i.e., why chosen, how data collected, etc.) before they can proceed to interpret the covariation. In this study even difficulty with understanding “light intensity” and how it might have been determined resulted in a breakdown in the interpretation. Thus, to interpret a graph as intended by the author, one needs to understand the axis labels, title, and caption as they are understood by the author. Here, “understanding” means that an interpreter relates these aspects of the graph to examples external to the graph and/or to common practices in a discipline. Students might have difficulty interpreting graphs because they are “acultural” in the sense that they lack (embodied) knowledge of subject-specific practices such as how “light intensity” might be measured. What interpretive experience they do have is cross-disciplinary (having taken science courses enfolding multiple science disciplines in high school)—which confounds their interpretation and makes it difficult for them to construct internally consistent interpretations because of the different practices in different disciplines.

To construct an internally consistent interpretation of a graph it appears necessary for the interpreter to possess a stable understanding of the graphs component parts and how the data was obtained. Experienced researchers moved transparently to consider the depicted covariation because they rapidly stabilized their understanding of the graphs components by drawing on many external references—populations they had seen or worked with, experiences they had heard related in stories by other researchers, practices they had engaged in, or conferences they had attended. If the graph interpreters lacked other experiences to relate to these aspects of the graph (e.g., variables on the axes) they rapidly experienced breakdown and ended up not discussing the covariation between the variables but instead focused on how variables were chosen and measured, other factors affecting individual variable variation, and graph construction.

Thus, experienced researchers generally enacted their interpretation differently than the pre-service elementary teachers and science graduates moving quickly to interpreting the actual covariation. However, the latter two groups, relying on references “inside” the graph and only rarely on those “outside” of the graph, did not consider the covariation in depth because they experienced breakdown when trying to make sense of the individual axis labels/variables, the influences on them individually, and how the data might have been collected. By relying on internal referents only and not stabilizing their understanding of terms, correlations, etc., with external referents any inconsistencies (such as between the trend lines and the caption) hindered interpretation by the pre-service teachers and science graduates.

Our interest is in how science courses and experience related to science research/teaching changes competencies in the tool-based practices of science, in part because organizations such as NSF propose that taking more science courses taught by scientists will increase this competency. The minor differences in interpretation we observed in this study consisted of science graduates demonstrating greater access to

domain specific language in their interpretations—however any differences in interpretations with those of the pre-service elementary teachers were generally unrelated to science undergraduate experiences. In general there were only minor differences in the graph interpretations of the two groups, and considerable dissimilarities between their interpretations and those of practicing scientists, suggesting that requiring education students to take more science courses in science departments will not have the desired outcome.

Significance to Science Teacher and Science Education

Effectively using graphs to construct scientific claims is an important component of the proposed curriculum reforms (AAAS, 1993; NCTM, 1989) that deal with inquiry-based teaching. Yet, evidence from this study (and others we have conducted) suggests that competency in interpretive practices does not derive from undergraduate science programs and thus that pre-service teachers would gain little increased competency at using graphs by taking science courses taught in science faculties. Lectures, typical fare in science departments, appear to be an ineffective way of enculturating students into graphing practices (Bowen & Roth, 1998b) thus, taking courses taught by science faculty would be unlikely to increase competency at using/interpreting graphs.

There are other implications for science education. Interpreting a graph problem seems to involve (a) resolving what the variables mean in real terms (b) resolving what affects the individual variables and (c) resolving the relationship between the variables. Usually, for an internally consistent interpretation to arise, interpreters need to make connections between/within the components of the graph (and/or question) and a series of external referents or examples. Not making these connections results in problematic interpretations. Further, any inconsistencies between what is stated in the question/caption and what relationships are portrayed in the graph also lead to students being stalled in their interpretation. This is important because in classrooms as teachers we often take students'

uncertainty about a relationship existing between the variables as evidence that they are not able to relate the variables portrayed in the graph. What the interviews in this study suggests is that breakdowns interpreting graphs occur at a much earlier point—before students have even considered the covariation—often related to the axis labels or inconsistencies between the graph and the question/caption statement. This means that for students to develop competency in using graphs as an interpretive tool we need to engage them in activities in which they interpret graphs as part of the inquiry process in which they determine variables, collect and summarize and interpret data, and defend their conclusions.

We also have to question (a) whether the objectives in our reform documents are realistic given the teaching practices in colleges and universities and (b) what kind of science experiences would better prepare preservice teachers with undergraduate degrees in science to meet the challenges posed by the visions of the reform documents. Grade 8 students, who engaged in their own research over two months developed considerable competency in framing, conducting and analyzing their own research (Roth & Bowen, 1994) and in interpreting and using inscriptions in the conduct of this research (Roth, 1996). Consideration of these studies provide insights into the types of science programs that might allow preservice elementary teachers to develop a competence of graphing as described in the reform documents—long term, independent inquiry project-oriented courses with peer review and critique addressing both the content and process issues of their science backgrounds.

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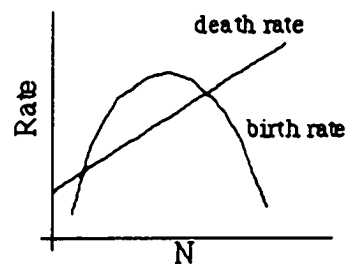
Table 1: Recommendations of The National Council of Teaching in Mathematics (NCTM)
about what Grades 5-8 mathematics curricula should enable students to do

-
- describe and represent relationships with tables, graphs, and rules; (p. 98)
 - analyze functional relationships to explain how a change in one quantity results in a change in another; (p. 98)
 - systematically collect, organize, and describe data; (p. 105)
 - estimate, make, and use measurements to describe and compare phenomena; (p. 116)
 - construct, read, and interpret tables, charts, and graphs; (p. 105)
 - make inferences and convincing arguments that are based on data analysis; (p. 105)
 - evaluate arguments that are based on data analysis; (p. 105)
 - represent situations and number patterns with tables, graphs, verbal rules, and equations and explore the interrelationships of these representations; (p. 102) and
 - analyze tables and graphs to identify properties and relationships. (p. 102)
-

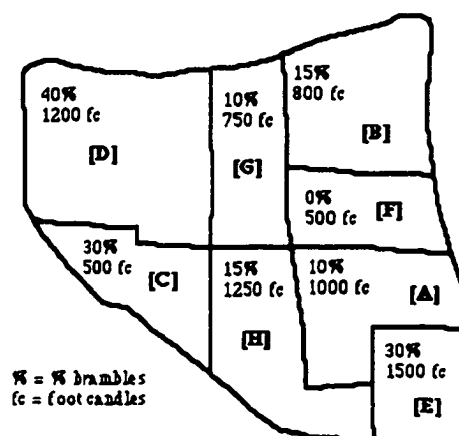
Table 2: Components in complete interpretations of each of the inscriptions

A. Population Graph	- isolation of intersection points as a significant feature - description of unstable and stable equilibria at those intersections - oscillation of population size (around stable equilibria point) - consideration of organisms behaviorally responding - distinction between graph representing empirical data vs. model - consideration of the effect of natural variation (data scatter)
B. Plant Distribution Graph	- juxtaposition of trend lines in relation to each other and the caption - anomalies in those trend lines compared to statements in the caption - difficulties in interpreting y-axis label (in relation to depicted data) - relation of 'preferred areas' of different plant types to the biology of the organism—adaptation, evolution, metabolism affecting plant survival, etc.
C. Lost Field Notebook Map	- data was plotted on X-Y scatterplot - outliers were checked for - correlation/regression analysis conducted/suggested (or trend line drawn) and visible patterns discussed - physical features affecting relationship were discussed (e.g., streams, shading hills, pathways). For field researchers correlation analysis was insufficient; the 'lay of the land' was also considered in relation to the correlation results

a. **Population graph** - In the derivation of the logistic model, we assume that, as N increased, birth rates declined linearly and death rates increased linearly. Now, let's assume that the birth and death rates follow a quadratic function (e.g., $b = B_0 + (k_b)N - (k_c)N^2$), such that the birth and death rates look like the figure. Such a function is biologically realistic if, for example, individuals have trouble finding mates when they are at very low density. Discuss the implication of the birth and death rates in the figure, as regards conservation of such a species. Focus on the birth and death rates at the two intersection points of the lines, & on what happens to population sizes in the zones of population size below, between, & above the intersection points.

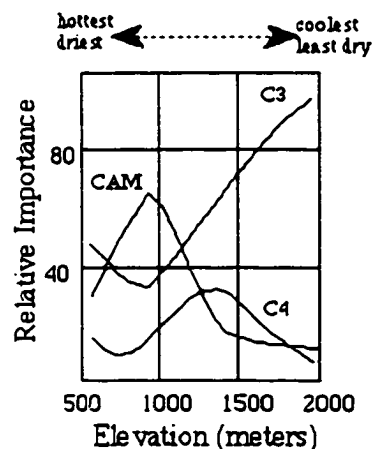


b. **The lost field notebook** - Elizabeth is a grade 8 student who is doing research on an ecozone. She wanted to find out whether there is a relationship between the density of brambles, a plant with a long narrow stem, and the amount of light these plants receive in different areas of her ecozone. She sub-divided her ecozone into smaller areas. In each area she measured the approximate coverage of the area (in %) by the brambles. For each area she also found the average amount of light, measured in foot candles (fc). She recorded her data in her field notebook in the form of a map reproduced below. Elizabeth lost her field notebook, and you found it. You wanted to know the patterns she had found, but besides the map there was no additional information. Based on the information provided,



1. what patterns, if any, do you see?
2. what claims would you make?
3. how would you support your claims?

c. **Plant distribution graph** - Distribution of C3, C4 and CAM (succulent) plants in the desert and semi-desert vegetation of Big Bend National Park, Texas, along a moisture and temperature gradient due to differences in elevation. CAM plants with nocturnal gas exchange for water conservation predominate in the hottest, driest environment, C4 plants are maximally important under intermediate temperature and moisture conditions, and C3 plants predominate at the cooler, least dry end of the gradient. (After data of W.B. Eickmeier [1978], *Photosynthetica*, 12, 290-297).



What implications can you draw from this graph?

Figure 1: Graphs, with accompanying written text, interpreted by participants

Chapter 5:

Lecturing graphing: What features of lectures contribute to student difficulties in learning to interpret graphs?

**Lecturing graphing: What features of lectures contribute
to student difficulties in learning to interpret graphs?²³**

Abstract

Some studies suggest that individuals having completed undergraduate science programs are often poorly prepared to use graphs in ways typical of their disciplines. Science and technology studies have identified competency in graphing as being of central importance to the practice of a scientific discipline. Given the centrality of graphing to the practice of science, an important aspect of becoming enculturated into the practices of a scientific discipline is being able to use and interpret graphs in ways that are typical to that discipline. For example, competency in this usage is important to reading, interpreting, and understanding journal articles in a discipline. Undergraduate science students spend a considerable amount of time in lectures where graphical representations play a major role in the presentation of subject matter. To gain an understanding of the use of graphs in lectures and how this use contributes to student understanding, this paper provides a microanalysis of graph use in lectures drawn from artifacts compiled from videotaping all lectures and seminars in a thirteen week ecology course. This analysis focused on both the text and the gestural references made in the reading of a graph in an ecology lecture. We conclude that the common ground existing amongst scientists that help them reach an agreed upon interpretation of a graph is missing from lectures and then discuss the constraints this places on student's learning about graphs in lectures.

²³ Previously published as Bowen, G.M., & Roth, W.-M. (1998). Lecturing Graphing: What features of lectures contribute to student difficulties in learning to interpret graphs? *Research in Science Education*, 28(1), 77-90.

Learning to use and interpret graphs in ways specific to a scientific discipline is an important part of becoming a scientist because of the central role that graphs play in scientific disciplines. Science studies suggest that graphs are important tools for scientists and central to the practice of the discipline (Knorr-Cetina & Amann, 1990; Latour, 1993; Lynch, 1995) both because they are useful for summarising large amounts of data in economical ways (Latour, 1987) and because they constitute the best tools to re-present covariation between continuous measures (Lemke, 1998). Despite this, relatively little work on graphing has been done in science education from an enculturation perspective and the teaching of graphs is typically not informed by sound theory (Lowe, 1993; Roth & McGinn, 1997; Schnotz, 1993). Competently interpreting graphs is also an important aspect of understanding scientific writing such as is found in journals because of the preponderance of graphical representations found in those writings (Roth, McGinn, & Bowen, 1997). In addition, the underlying mathematical structure of graphs is partly responsible for further enculturating students into the central belief in science: nature has a mathematical structure so that an unambiguous mapping {Fundamental Structure $\longleftrightarrow$ Mathematical Form} can be made (Lynch, 1991).

Science studies research suggest that context is an integral part of being able to interpret graphs and that it derives, in part, from their original construction. Graphs help establish the isomorphism {Fundamental Structure $\longleftrightarrow$ Mathematical Form} by data progressing through a series of transformations before their final graphical representation is reached. Yet for any phenomenon, between two consecutive transformations there exists an ontological gap which is not present in any of the writings about the representation (Latour, 1993). The result of these now invisible transformation practices is an isomorphism that appears to have existed all along. But, if one has constructed such representations before, then a distinction must be made between “invisible” and “non-existent.” In this distinction, “invisible” suggests that the series of transformations is tacitly recognised by the

interpreters of the final re-presentation and is part of their interpretive framework. “Non-existent” means that the interpreter is unaware that such ontological jumps are being made as the data progresses through the transformations and does not take them into consideration in the final interpretation. Our work with scientists from different disciplines suggests that the assumptions made about the discontinuities between transformations are integral to the interpretation of graphical representations (Bowen, Roth, & McGinn, 1997; Roth & Bowen, 1998).

Students of all ages have difficulty using various representations appropriately, especially graphs (Leinhardt, Zaslavski, & Stein, 1990; Schnotz, 1993). Even many science students (often touted to be the most able of university students) have difficulty using graphs. In one of our studies, students in a second-year ecology class experienced difficulties interpreting graphs in their seminar period (Bowen, Roth, & McGinn, 1997); in other studies, individuals who had already obtained BSc and MSc degrees demonstrated difficulties interpreting simple data sets through transformations into graphical representations (Roth, McGinn, & Bowen, in press; Bowen & Roth, 1998).

The centrality of graphing to the practice of science suggests that there is merit in examining how undergraduate science students, who represent those most interested in adopting scientific practices, learn to interpret graphs. In undergraduate science programs the most frequent type of class encountered by students are lectures conducted by a professor or instructor from the front of the room. It is in this venue that undergraduates can learn about graphs: instructors use graphs to present facts and frequently model how to read graphs. For the past several years our research group has been examining the training of scientists along the trajectory proceeding from elementary school to postgraduate studies determining how and when they develop competencies in scientific practices—especially the production and use of graphs—and has found that students have difficulty using graphs at most education levels. Although learning to interpret, produce, understand, and

otherwise use graphs is critically important to becoming an ecologist, little work has been reported on how undergraduate students come to develop this understanding. Given that graphs are encountered frequently by undergraduate ecology students—in this course we counted, on average, 19.3 graphical representations (and 25.5 inscriptions in total) per 50 minute lecture—the question arises as to why students experience difficulties with graphs. To try to understand why these difficulties occur, we conducted in the present study micro-analyses of those moments in the lectures where graphs played an integral part.

Research Design

In this article, we analyse a professor's lecture talk over (with) and about graphs to understand what makes it hard for science students to appropriate graphing practices. Our analytic methods were informed by those used in sociological and ethnomethodological investigations of scientific work (Latour, 1993; Suchman & Trigg, 1993; Woolgar, 1990). Our study was not concerned with the instructor per se, for lectures are typical of what students encounter in science lectures (e.g., Roth, McRobbie, Lucas, & Boutonné, 1997; Roth & Tobin, 1996)—in fact, our observations confirmed that this course was better prepared, designed, and conducted than most science courses we encountered as students and as observers. Rather, our analysis focuses on structural properties of the lectures in general and the role graphs play in them. As a member of a culture, the lecturer merely represents practices common in the enculturation of students to the discipline of ecology (and other sciences) and this analysis should not be viewed as any indictment of the particular lectures analysed.

Data Sources

To gain an understanding of the use of graphical representations in lectures and the enculturation of students into the practices of science, we compiled an extensive database of artifacts produced in a second-year undergraduate ecology course. The database from which this analysis was primarily drawn consisted of videotapes of all 39 50-minute

lectures of a second-year introductory ecology course, lecture notes and overheads obtained from the professor, copies of the class notes distributed to students at the beginning of the semester, and the field notes recorded by one of the authors (Bowen) at the end of each lecture. Our analysis of the lectures also drew on videotapes from the three fifty-minute seminars held each week for 12 weeks, videotaped interviews with students and scientists, field notes from informal discussions with students and with the teaching assistant, and copies of students' mid-term and final exams. Videotapes and audio tapes were transcribed in an ongoing manner to allow for preliminary analysis that guided the collection of relevant additional data.

Data Analysis

Our analysis was based on the assumption that reasoning is observable in the form of socially-structured and embodied activity (Garfinkel, 1991; Heidegger, 1977) and therefore followed precepts of interaction analysis (Jordan & Henderson, 1995), semiotics (Bastide, 1990) and hermeneutics (Gadamer, 1975) of scientific texts.²⁴ In our analysis, videotapes of the lecture and their transcripts were considered to be natural protocols of lecturing work.

From our transcriptions of videotapes, lecture notes, and field notes we identified topics of interest to our research agenda. Using interaction analysis, we re-viewed the videotape segments together taking preliminary notes and discussing significant events. The video segment for this paper was chosen because it is representative of the patterns we identified in the data corpus more generally. As a check of our own analyses, we conducted a group analysis which included faculty members and graduate students in education. Videotape replay was stopped whenever a member of the group thought a significant event had occurred; the event was reviewed as often as necessary so that each tentative assertion

²⁴ For this type of analysis, graphical representations are considered to be (a) another form of "text" and (b) provide the context of the talk (cf. Geertz, 1973; Ricoeur, 1991).

could be explored by all researchers allowing us to test our interpretations against those of a larger group.

Interpretations of graphs and lecture contexts was enhanced by the different academic backgrounds of the two authors (Bowen as an ecologist, Roth as a physicist) and those who participated in the group analysis (e.g., psychology, science and mathematics education, ecology, media analysis). The sharing and critiquing from these different perspectives helped guard against non-viable interpretations of the data and made us aware of our own constructions and assumptions. Using a heterogeneous team provides advantages to the analysis for there are issues that might be overlooked by insiders (natives) in ecology (such as Bowen), but not for outsiders to the community (such as Roth). At the same time, there are context-specific particularities that require insider knowledge to become noticed. In our collective analysis, we therefore played insider/outsider knowledge against each other to evolve a deeper understanding of the intricacies of the presentation and role(s) of the graphs in that presentation. After the group analysis we constructed our individual interpretations and convened to re-examine our independent analyses. Our individual constructions were discussed and subjected to critique and analysis, so that each could be examined against the understandings of both authors. From these discussions we formed tentative assertions which were then tested against other episodes in the database to determine the degree to which they confirmed or disconfirmed the assertions. We used these checks to reformulate the initial assertions until they were representative of the complete data set. The interpretation reported here emerged from many such interactions.

Introduction to the Metabolism of Photosynthesis

To aid readers in their understanding of the concepts presented in the lecture segment, and to contextualise our analysis, we provide a brief introduction on the topic being

discussed in the lecture (cf. Ricklefs, 1990).²⁵ Water loss is a significant problem to plants in some environments and less of a problem in others. This is partly because of differences in rainfall, but also because the vapour pressure of water increases with temperature thus magnifying water loss in hotter environments. In dry environments various physical adaptations are found in plants which reduce water loss (e.g., waxy surfaces on the leaves and reduced leaf surface area to the point of having spines instead of leaves). Although many people are familiar with these physical adaptations, they are much less aware of physiological adaptations to dry environments. These are related to the metabolic pathways utilised by plants to assimilate the carbon in carbon dioxide into an organic molecule. Changes in this metabolic process can increase the efficiency of assimilation thereby reducing the time the stomates (pores to the atmosphere through which considerable water loss can occur) need to be open. Another type of metabolic adaptation is the assimilative process being divided into two stages so that the stomata are only open in the evening when cooler temperatures reduce the water loss due through the stomates. The three types of metabolic process discussed in the following lecture segment are C3 (found in plants which do not need to conserve water), C4 (which conserves water but is less energy efficient), and CAM (which has the two part process divided between night and day).

[INSERT FIGURE 1 ABOUT HERE]

The graph used in the lecture (Figure 1a) represents the relative distribution of plants with these three different types of metabolism at different elevations in Big Bend National Park in Texas. Plants with C3 metabolism are found at the highest elevations (which are also cooler and moister), those with C4 metabolisms are found most frequently in mid-elevations (which are more moderate for temperature and precipitation) but not more than

²⁵ Another reason we selected but one excerpt for analysis is the complexity of the different subjects which would require extensive explanations of each concept in this article.

C3 plants, and those plants with CAM metabolisms dominate at the lowest altitudes (which are also hotter and drier than higher altitudes).

Lecturing about Graphical Representations

The place where students become enculturated to graphing-related practices, apart from their use of graphs in seminars and when solving word problems (which we have examined elsewhere (Bowen, Roth, & McGinn, 1997; Roth & Bowen, 1998), is in their lectures. Professors and teachers frequently use graphs when instructing students in lectures and students frequently do not understand the various graphs used (Roth & Bowen, 1997, 1998; Roth, McRobbie, Lucas, & Boutonné, 1997; Roth & Tobin, 1996; Roth, Tobin, & Shaw, 1997). The present paper continues our investigations into the cognitive complexities of lectures focusing on the presentation of graphical representations to better understand why students seem to learn so little about graphing.

The talk over and about the graph in the following episode is typical.²⁶ The excerpt represents the entire two minute and fifteen second presentation of the graph (Figure 1a). The graph was offered as a real world example of the effects of different types of photosynthesis metabolism on plant ecology.

- 01 **Lecturer:** Now we can see the effect of these different types of metabolism on
 02 distributions of plants in this next overhead. (Overhead) Here we
 03 have a moisture and elevation gradient in a transect, which is actually an elevation
 04 gradient but here elevation is closely associated with moisture and temperature.
 05 The low end, it's more or less desert, it's very hot and dry. You get up higher
 06 in the mountains and it's cooler and wetter.
 07 **Student:** Is that in our text? Is that in our text?
 08 **Lecturer:** This is not, but it's a very simple pattern. The main point here is

²⁶ The graph is also "about" the narrative. The graph and narrative mutually constitute the story being told about the relationship between plant metabolism and distribution in different climes.

09 really quite simple. And this is just showing you the distribution of numbers of
10 plants that have different types of metabolism. Where it's coolest and least dry, in
11 a rather silly way of saying wetter, relatively more C3 plants. Where it's sort of
12 intermediate here and intermediate temperature, intermediate dryness you have
13 relatively more C4 plants. And where it's extremely hot and dry, because this is
14 South Texas after all, we have relatively more CAM plants. So these metabolic
15 differences happen to have strong effects on distribution of the plants. And
16 recently people have got quite interested in the question of how will these different
17 types of plants react to increase of CO₂ entering the atmosphere? Will increased
18 CO₂ tend to tip the balance between these in any way as a result of their different
19 way of how this CO₂ is used? People really don't know yet, they have some ideas
20 about what you might get C4 plants, for example in here to do relatively better, but
21 it's an open area of research and it's really quite an important one with CO₂ and
22 the temperature going up. Any questions about the C3, C4 and CAM?

Our analysis of students' use and interpretations of graphs show that they understood little about the graphs use in lectures and could not interpret or use them. Moreover, it became quite clear in a seminar attended by doctoral students and professors that well-educated people had difficulties following this (for scientists) rather simple graph. What features of this sequence of text make it complex for listeners to follow? We address this question by examining the text and related graph in two ways. First, we discuss the variables present on the graph and in the lecture, their relation to each other, and the transformations they undergo in the lecture. Secondly, we conduct a micro-analysis of the movement of the professors hand as it emphasises which sections of the graph the students should attend to as he is lecturing.

Discussion of Variables

In explaining the implications of C3, C4 and CAM photosynthesis on the plant distribution numerous variables were presented. Many of these variables were drawn from the graph itself, but others were introduced based on the lecturer's personal experiences which serve as interpretive resources. These experiences include aspects of the type of research work that gave rise to the graph and also research experiences involving multiple variables found in the framing and solving of research problems. Students generally had far fewer of these interpretive resources for making sense of graph and narrative (Bowen, Roth, & McGinn, 1997).

The lecture text introduced the graph as an example of the ecological implications of the different types of photosynthetic metabolisms found in plants and presented earlier in the lecture. The text (lines 01 and 02) describes the graph as depicting a relationship between metabolism (independent) and plant distributions (dependent variable) including three categories of metabolism. In lines 3 and 4, additional variables are introduced: an elevation transect which is highly correlated ("closely associated") with moisture and temperature. Rather than a single dependent variable to consider, listeners have to continually process not just relations between the three metabolism types and their distribution, but relationships within the distribution as well—covariation between moisture, elevation and temperature. It is now unclear if the variation in distribution is caused by differences in elevation, in temperature, or in moisture. The relationship between distribution and metabolism is considerably less clear as the variables related to distribution have been mapped on top of each other. From an information processing perspective (e.g., Anderson, 1985), this mapping makes it more difficult to understand the text in real time because the variables along the transect are not beside each other but are separated with the climate variables being located at the top of the graph and the geographic variable (elevation) being located at the bottom (Figure 1a).

To scientists familiar with covariations between climate variables and elevation this is a “simple” graph (line 08): plants with different metabolisms have different distributions along some climatological cline. But to newcomers, graphs such as this are anything but simple because of the number of factors that must be considered simultaneously when trying to understand relationships. A further layer of complexity is added when one of the climate variables (line 10 & 11) is transformed from being “coolest and least dry” to having the alternate meaning of “wetter.” Such transformations add another detail to be considered in constructing an understanding of the relationship between metabolism and distribution.²⁷ In the lecture text, the different variables substitute each other. However, members (lecturer) and non-members (listeners) in the ecology community have different referents for doing this substitution; this makes it a less transparent process for non-member listeners and something to which they must continually attend.

Intrinsic aspects of the graph contributed to its difficulty relative to non-members. It is common knowledge in the ecology community that plant metabolism causes plant distribution to vary with climate. Yet, the scale of reference for the climate variables (the correlated moisture and temperature) are at the top of the graph and represent a relative scale. Correspondingly, on the y-axis the scale is not one of plant species number, density, height, health, or some other measure which could be clearly correlated with climate features but is instead “relative importance.” Hence, the audience observes a relationship between metabolism and distribution which appears, on the surface, to be a qualitative, not necessarily linear, relationship and which is therefore less clear.

Using these relative scales adds to the interpretive difficulty in determining the referents in the examples. There is no easy way to interpret the “relative importance” of the different

²⁷ In a stricter ecological sense, there is also the question of whether “least dry” does equate to “wet” (which is the implication of using the word “wetter”) which raises a further point for listeners to think about. They not only have to remember to make that transformation when interpreting the graph, but also need to consider the implications and correctness of that interpretation.

plants because it is not obvious over what distance the transect was done²⁸ nor what species or types of plants were examined. Further, the relativity of the scales forces the existent patterns to be referred to in a relative fashion as well. In our interpretive sessions we listened to the videotaped segment transcribed in lines 11 to 13 repeatedly because we had conflicting interpretations of the references made to the term “intermediate” as it was used. One interpretation takes its meaning from the first use of the word “intermediate” (referring to the up-down y-axis position) and a different meaning from the second and third usage (referring to being midpoint on the upper x-axis). The other interpretation took all three uses of “intermediate” as referring to the upper x-axis. Which of these interpretations was the intended one remained unresolved despite repeated viewing and suggests that such interpretive flexibility could also be experienced by other listeners as well. Thus, the audience needs to attend to multiple sources of information at once (notes or note taking, the projected graph with its captions, the lecturer, and the lecturer’s hand movements) which affects their understanding the directions guiding the graph’s interpretation.

Lecturers, as members of the knowledge community, also bring experience-based interpretive resources to the task of understanding graphs that are unavailable to non-members. For instance, in this lecture a reference to the climatological and geographic features of the area (lines 05-06) and the statement “this is south Texas after all” hint at the personal experience of the lecturer in that area of the world that was integral to his understanding of the graph. This experiential background in the area, which was separated by some distance from the university at which these students were being instructed, suggests that interpretive resources unavailable to the students were being used to help understand the graph.

²⁸ Student experiences with transects in first year courses are typically those done over 10-30m. We question whether this experience would translate into understanding how a transect over hundreds of kilometers was conducted.

The lack of common interpretive resources here is important because of the importance we have concluded that they play in other studies we have conducted. Even in the case of relatively simple graphs, field ecologists elaborate their interpretations by using a large number of personally relevant interpretive resources. In providing their interpretation of graphical inscriptions they cycled back and forth between actual scenarios with which they were familiar making sense of the graph through their familiarity with their own experiences (Roth & Bowen, 1998). We observed a reflexive relationship between ecologists' experiences in the field (such as visiting Big Bend National Park), their knowledge of models, and their familiarity with the actual scenarios they were considering. This is significant in relation to this study because listeners to a lecture about graphs cannot engage in the reflexive elaboration that allows members to be 'experts' at graph interpretation.

Physical Directions to Guide Interpretations

In this section we provide an interpretive analysis of the gestures accompanying the verbal text, and which provided background to his interpretation of the graph for the students. For an individual, viewing and interpreting graphs is not a process which occurs spontaneously or automatically. Within particular communities of practice (here ecology), graphs are treated as containing significant amounts of information condensed in such a manner that it makes them an efficient tool for looking for and transmitting information about relationships between variables. However, this "packing" of information into a viewable representation means that the reverse process must also occur—viewers must be able to unpack that information to be able to talk about patterns apparent between the variables (Roth & Masciotra, 1998). When non-members view graphs and are asked what they mean, they are essentially asked to reconstruct this information and interpret any relationships between variables. This reconstruction occurs through focusing on community-specific information portrayed in the graph structure (e.g., axis labels, scales,

etc.) and relating it to the patterns in the data depicted in the central part of the graph, in the case of this specific graph the lines representing each of the types of metabolism. Learning to interpret graphs means that non-members must come to see and understand which features of the graph are relevant and important within the community.

We interpreted the lecturer's gestures as being of three general types. First, the most general gesture was "movement." This usually occurred as an action between the next two types of gestures or as an indication of the lay of a line of data or best-fit (Figure 1b). The second type of gesture consisted in pointing to "resting points" at the surface of the overhead acetate. These were the locations at which the pen stopped moving to emphasise a particular point on the graph. This stopping (pointing) had the effect that it directed attention and made the verbal point being made more salient bringing to the fore potentially hidden 'aspects' of the graph. For instance, the second and third use of the word "intermediate" (line 12) and the referent to which they applied was emphasised by the pen movement halting and 'tapping' the acetate at the midpoint location of the x-axis (upper) to which their usage referred (Figure 1b).

The third form of gesture was that of "reference points" which were verbally accentuated areas over which the pen currently moved but did not stop. These "reference points" often occurred at an apex where the pen movement "turned" in its direction. This type of gesture was more ambiguous in its reference to the graph and provided for considerable interpretive flexibility. For instance, the first use of the term "intermediate" (line 07), as discussed above, was open to interpretation with respect to which axis it referred. The "turns" at the left and right and also at the vertical apex of the pen movement around when this word was spoken (Figure 1b) do not identify an unambiguous referent.

Two episodes of movement from the text that make understanding graphs more difficult are examined. Together they are representative of the types of gestures made whenever a graphical representation was used in lectures. In general, one of these episodes detail

movements which make unclear references to the sections being discussed and the other details asynchrony between what is said and the aspect being talked about and foregrounded by the gesture. In the first episode, the text provides a literal reading of one of the three curves (lines 11-13). We already showed how this textual part of the lecture was ambiguous. To understand why, we transcribed the hand movements which correlated with the text of the lecture (Figure 1b). The gestures viewed concurrently with the text provides us insight into this interpretive flexibility.

The first use of “intermediate” coincides with a left to right inverted ‘vee’ gesture along the line representing C4 plant distribution. The second and third use of “intermediate” coincided with pointing gestures on the middle point of the line that represented the transition from hottest/driest to coolest/least dry (“wettest”). Although the second and third usage have an unambiguous referent in the midpoint of the top-axis scale, the first use of “intermediate” could be interpreted as either demonstrating the up/down intermediate position of the peak or the left/right position along the hottest/driest to coolest/least dry continuum. In our analysis, following the text with the hand movement, even in repeated viewing, did not resolve the issue which of the two interpretations “intermediate” was to be selected by members of the audience—one can interpret it either as emphasising the intermediate vertical distance or as emphasising the intermediate (left-right) position of the climatological features.

The second episode demonstrates another frequent occurrence in the lectures—asynchrony between the referents of the hand movement and the narrative content. Asynchrony can lead to misinterpretations because there exist conflicts between text and visually available referent—they can each represent different topics or sub-topics of what is being discussed. Asynchronies in the lectures occurred in three ways. They occurred when hand movements were ambiguous (in other words, reference a point on the graph that is not clearly connected to the narrative), preceded or followed referent. Although all three

types of asynchronic gestures occurred throughout the lectures, in this particular segment of the lecture there are examples of two types that were particularly noticeable in our analysis.

The first occurred as the lecturer was segueing from the three types of metabolic pathway to an ecological example of those different metabolisms. The new graph was described as, “Here we have a moisture and elevation gradient in a transect” (lines 02-03) during which the pen pointed towards text in the caption.²⁹ The text cued listeners to the graph itself, but the pen pointed to the text of the caption. The caption text did not indicate that data were collected along a transect, so while the lecture continued with a discussion of the graph, listeners would have to refer to both the caption and the graph to determine how a “transect” was used to collect the data.

A second type of frequent asynchrony occurred 60 seconds later in the lecture where a gesture preceded its textual reference. The gesture of pointing at the “CAM” label occurred simultaneously with the utterance “. . .and where it’s extremely hot” (line 13). The text does not enunciate the label for another seven seconds. Such a long break, particularly with the interceding comment “this is south Texas after all” again serves as a distractor to following the interpretation of the graph. Cognitive psychological research suggests that if cue and target are separated by more than 400 milliseconds, information becomes more difficult to process (cf. Anderson, 1985).

There are also examples of the text and the attention directives being synchronous. This mixture of synchronous and asynchronous gestures makes it difficult for non-members but unproblematic for members to follow the reading of graphs. If listeners know that the gestures are asynchronous relative to the text, they can decide not attend to them (Goodwin, 1986). However, with gestures being both synchronous and asynchronous,

²⁹ Our ethnographic fieldnotes show that caption texts were generally unreadable for at least the back half of the classroom because of the distance from the overhead to the projector screen.

listeners must evaluate each and every gesture and try and determine if each refers to current narrative, past narrative, or has any reference at all in the graph. Time and cognitive processing spent on these tasks is then not spent on the task of interpreting the graph itself. In effect, providing listeners with interpretive guidance such as found in this segment (and not uncommon to that found in other lectures and with other professors) means that listeners have dual processing tasks since they must work to interpret the gestures themselves as well as the graph as well as simultaneously attending to the narrative flow.

Discussion

Science studies research provided a small number of detailed analyses of how scientists review and understand graphs. In one study of the “craft-based skills of laboratory work” of solid state physicists, Woolgar (1990) focused part of his analysis on the use of representations in the laboratory and the role these representations played in the interaction of lab members. He found that the interpretation of temperature (line) graphs by two physicists depended on a considerable number of common interpretive resources, “. . . the apparently simple action of reading temperature trades on an entire chain of unquestioned connections” (p. 135). These mutually understood common contexts provided the foundation for the achievement of a common agreement on the temperature graph’s meaning. In relation to the present analysis, the implications of this sociology work in laboratories are significant. Woolgar’s scientists reached a common interpretation of the meaning of the trace because of their common experiences in having constructed such traces through their actions in the laboratory. It was their collective *activities* and the discipline-specific dispositions (Bourdieu, 1997) that provided the foundation for a common interpretation. Lecturer and the original constructor of the graph are members of the same community who are enculturated in the use and construction of representations in general and share experiences with the same geographic area. Non-members normally have fewer interpretive resources for tying variables together and as such have little common

ground with the individual who constructed the original graph; they neither visited South Texas nor constructed similar line graphs in their own research work.

Interpreting graphs and relating the information they encoded in the community to 'nature' are important practices that becoming ecologists have to appropriate. We provided evidence elsewhere that students do not learn to relate graphs to nature in the same manner as do practising field ecologists (Roth & Bowen, 1998). At a more fundamental level, the present article examines how the narrative component of a lecture and gestures used within it act together to provide directions to students in their learning how to interpret a graph. From an insider perspective, using a graph is a reasonably straightforward process and the instructions provided (both narrative and gestural) for interpreting the graph were sufficient. However, from the perspective of newcomers to the discipline (i.e. students), the lack of specificity in the narrative requires listeners to both interpret the gestures themselves as they related to the text of the narrative as well as the graph itself. This is not, however, an interpretation of the epistemology of learning about graphs that is apparent to most science instructors. One biology professor indicated to us that he expected students graduating from his course would be highly proficient in graphing. He also expected that students would default to graphs automatically in appropriate situations, because he had lectured about using them a lot and had provided interpretations of graphs in lecture.

For the audience of the present lectures, graphs lay outside their everyday experience and the social roles that helped construct the graphs in the first place are not ones in which they have participated. As initiates, the social aspects of the graph's original construction, and therefore its interpretation, do "not lie 'in' the representation itself, but in its roles in relation to the activities of persons in the world" (Pea, 1993, p. 62). Interpretations of a graph lie not in understanding the representation itself as a static object but rather in understanding the social actions through which the graph was originally constructed. An understanding of the social actions does not arise from an explanation of the components of

the graph itself but are implicit in the dispositions and habitus of a domain which are appropriated by tacit modes of learning (Bourdieu, 1997). For practising field ecologists, graphs are tools for constructing understanding of the environment just as for carpenters hammers are tools for joining pieces of wood. The parallel is important, because it allows us to compare learning to graph with learning to hammer. Winograd and Flores (1987) argue that, "In driving a nail with a hammer (as opposed to thinking about a hammer), I need not make use of any explicit representation of the hammer. My ability to act comes from my familiarity with *hammering*, not my knowledge of *a hammer*" (p. 33). Similarly, we argue that it is not the knowledge of a graph which is important (such as being able to identify the axes) but rather the competence to use graphs for displaying data, looking for trends, and constructing scientific arguments that are important.

Graphing is an important tool for navigating the conceptual world of ecology. Learning to navigate this world means to develop competencies in doing the navigating, not observing the navigation done by others. Lectures do not provide the forum for embodied practising of this navigation through the use of representations that are provided for in laboratories and seminars. Students need to interact with others over and about graphs, not just look at them because it is difficult to become a competent graph user by watching someone talk about a graph. Rather, one becomes a competent graph user by constructing them, making sense of data, and constructing arguments from it (Roth, 1996). Lecturers move easily through the conceptual domain of graphs because of familiarity with their context (e.g., geographical, use as a scientific tool, etc.) but for students who are newcomers to this domain, such movement is not so easy. In fact, videotapes of students' interpretations of graphs in seminar showed their use of them to be anything but straightforward (Bowen, Roth, & McGinn, 1997). We should also point out that these problems do not exist just in the domain of ecology alone. Very similar processes of teaching about graphs were found in an introductory physics course for education majors

taught by a 20-year veteran of physics teaching (Roth, Tobin, & Shaw, 1997) with similar difficulties found from the interpretive approach of students. What is clear is that the teaching of graphing needs more than just common conceptual ground.

For science students lectures serve the role of providing a focus in the wide range of topics and subtopics within ecology which they can use to guide their own (later) studies. With graphs, the expectation is refined to not just guidance on which graphs to pay attention to, but also guidance in how to interpret those representations. When there is considerable asynchrony, such as when the gesture indicated the caption text and the lecture text was referring to the graph, listener attention is divided so that the visual references and the aural references are being processed separately, as opposed to simultaneously, which can contribute to the cognitive complexity of coming to understand that representation. Given that the lecture text takes the axes as its topics, the gesture acts as a distractor as opposed to a focuser because listener attention is diverted from attending to the axes, an integral component of interpreting graphs.

The common ground that developed through conversation between the scientists in Woolgar's study (1990) and which allowed for them to reach a common interpretation of a graph does not exist in lectures, in part because lectures don't usually provide an opportunity for negotiating this common ground. Therefore, in ideal lecture situations you would need better synchrony between text and gestures. However this may be impossible to achieve because of the irremediable indexicality of language which always means more than can be said in so many words but also leaves much unsaid. Teaching about graphs needs not just common conceptual grounds, which students may be developing, but common experiential ground as well (Roth & Masciotra, 1998). These two types of grounding are inextricably linked in becoming enculturated into the graphing practices of a domain, yet the experiential component, such as existed between the scientists in

Woolgar's work, is often lacking in the education of undergraduate science students and does not exist in lectures themselves.

The lecturer in this course freely moved around the domain of graphing as it related to the conceptual areas of the subject, in ways in which the students were unable to do given the experiential and conceptual resources on which they could draw. Thus, from a social practice perspective, it is difficult to claim that lectures are an effective format for students learning both about the conceptual material of a domain especially that supported by the representation practices of that domain. In part then, this paper is an argument for an epistemology of action, a *knowing-in-action*, by which students become enculturated to the representational practices of the domain (and consequently the conceptual relationships) by engaging in the purposeful use of graphical representations. Of more utility than lecturing about graphs would appear to be the asking of students to engage in investigations in which they use graphical representations to construct relationships based on collected data and which they then support and construct claims from by reading and relating a variety of related written resources (which includes graphs). Presentation (and defence) of these representations and associated claims in seminars would then offer the opportunity to scaffold student understanding of both the representational practices and the conceptual content of the domain as the students participated in a community in which graphs have meanings that relate to their domain-related roles. This type of seminar is often found in science departments, but is often a "special" course taken by a minority of students. There is further irony in that the current structuring of undergraduate science programs is often such that these types of seminars are not offered until the third or fourth year of studies, after students have been lectured to about graphs, with questionable effect, for over two years of post-secondary schooling.

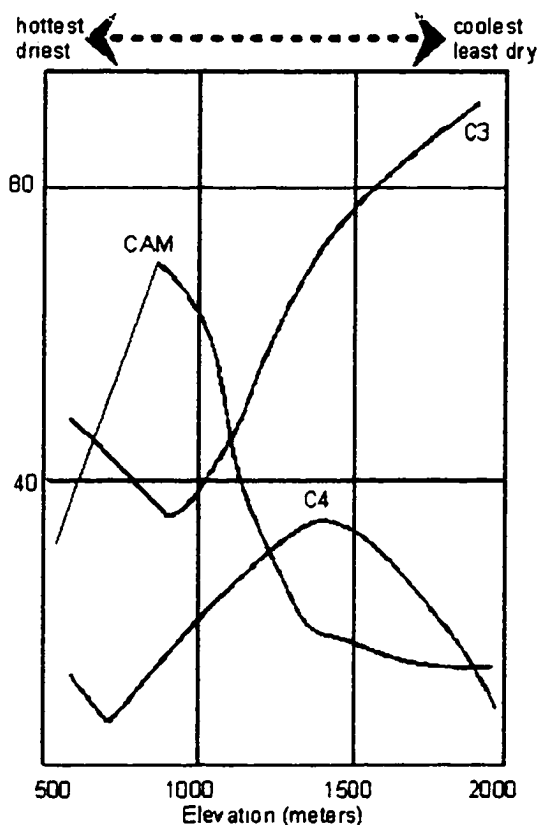
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1a

1b

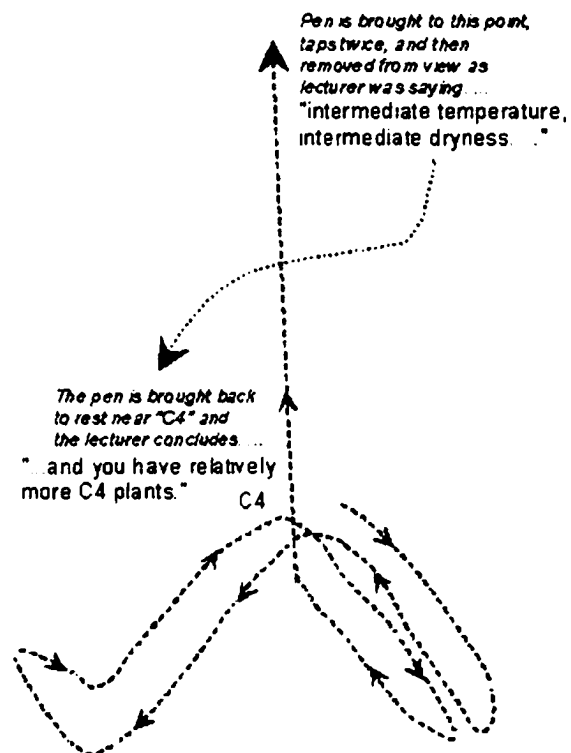


Figure 1. a. Graph used in lecture for talking about distribution of C3, C4 and CAM plants in the desert and semi-desert vegetation of Big Bend National Park, Texas. After data of W. B. Eickmeier, *Photosynthetica*, Vol. 12, pp. 290-297, 1978. b. Trace of pen movement, actions, and text in the literal reading of the C4 line.

Chapter 6:

Why do students find it so difficult to interpret scientific inscriptions?

Why do students find it so difficult to interpret scientific inscriptions?

Abstract

Our research examines the trajectory of individuals from high school to professional practice in science activities. While on that trajectory, students use a series of scientific writings as part of their education into the concerns, practices, and knowledge claims of science. This study examines the inscriptions in the written resources available to students in high school and undergraduate science courses: textbooks and journal articles. Four complementary analyses of their content are presented: (i) enumeration of the types of inscriptions in those resources, (ii) semiotic analyses of the content of representative inscriptions, (iii) interpretation by graduates of a science program of an inscription common to all three resources, and (iv) a comparison of an inscription found in textbooks and lectures with its original journal usage. Differences exist in frequency of different types of inscriptions in the different resources which are unrelated to interpretive competencies of the students for whom they are intended. Alterations in inscriptions as they move from professional journals to textbooks actually confounded interpretation. Implications for both science education and the use of inscriptions in textbooks are discussed.

In recent years, the notion of inscription—including graphical and pictorial representations, graphs, data tables, maps, diagrams—has gained increasing importance in understanding scientific representations and their use (e.g., Roth & McGinn, 1998). A number of studies (e.g., Knorr-Cetina & Amann, 1990; Latour, 1993; Lynch & Woolgar, 1990) have highlighted the pivotal role inscriptions play in science as process and product. From the use of tables while collecting data to the construction of elaborate causal models developed from the findings of many studies, inscriptions play a major role in scientific research, analysis, interpretation, fact construction, and modeling. Inscriptions are so central because they easily be cleaned, transformed, superposed and labeled; this allows easy inclusion as an evidentiary base into research articles (Latour, 1987; Lynch, 1990). As part of scientists' argument construction, physical phenomena are translated through series of inscriptions that are at once more inclusive but also more distance from the direct experience with the phenomena. It is through these translation processes and the resulting inscriptions that scientists both construct and "see" phenomena.

Ethnographic research among scientists shows that inscriptions do not merely represent data, but are a central aspect of the topology of scientific vision (Roth & Bowen, 1998). That is, representations are both the means to bring to life some phenomenon and a support for its existence: They are both eye and data collected by the eye. Later, when included in texts, inscriptions are embedded in such a way that they lend support to the written claims (Lynch & Woolgar, 1990). Captions and main text are constructed so as to limit readers' interpretations. Scientific writing essentially coerces their audiences into understanding the argument/claim and representation as being plausible reinforcers of each other at the same time (Bastide, 1990).

There is evidence that interpreting inscriptions is not an easy task (Schnotz, 1993). Yet, despite the importance of inscriptions in science and the large range of possible functions they could perform in instruction, little is known about how people know, understand, and

learn about graphical representations and other inscriptions; there is little research evidence that they are effectively utilized to the extent that is possible (Mayer, 1993; Peeck, 1993). The use of graphs and other types of inscriptions is something which students of all ages have difficulty using appropriately (Leinhardt et al., 1990).

Our research agenda is concerned with the development of competency in scientific practices, including research and representation practices. As part of this research, we have examined student (middle school, high school, university) competencies at interpreting graphs and contrasted their analyses with those of “scientists” who conduct their own field research (e.g., Roth & Bowen, 1999). In part, we conduct this work to examine trajectories of competency as students proceed from having little experience with the practices of science to being able to conduct scientific research as members of a community of researchers. As part of this research we research in school and university classrooms and conduct ethnographic studies among ecologists and environmental activists. So far we already identified several characteristics of lectures (in which inscriptions are used) which contribute to difficulties students have in learning to use inscriptions effectively (e.g., Bowen & Roth, 1998). For example, we identified four types of problems related to graphs in lectures (which hold across subject and educational level): (i) lecturers presented inscriptions qua signs as if they pointed to their scientific community’s agreed-upon referent in a transparent and therefore unproblematic way; (ii) lecturers presented problematic translations into their explanations intended to facilitate student understanding; (iii) graphs-as-models and graphs-as-best-fit remained indistinct; and, (iv) lecturers never disclosed the concerns and purposes underlying the use of particular inscriptions in the first place but presented these as matters-of-fact. Further, by videotaping students as they interpreted graphs in their seminar groups we found that they experienced considerable difficulty in interpreting inscriptions and we came to better understand where these breakdowns in understanding occur (Bowen, Roth, & McGinn, in press).

Given the importance of inscriptions in science, it is hardly surprising that they are predominant in scientific texts and lectures. On average there are approximately 1.4 inscriptions page in high school textbooks and journal articles (Roth, Bowen, & McGinn, in press) and 25.5 per 50 minute lecture in a university course (Bowen & Roth, 1998). Textbooks and lectures constitute the primary sources where science students encounter inscriptions. Because science teaching at almost all educational levels is dominated by textbook-textbook-oriented approaches (Tobin, 1990), Good (1993) recommends that “Far more research should be done to provide consumers (e.g., science teachers and principals) with better information about curriculum materials” (p. 619). The presentation of graphs in the formal texts of science teaching, whether written in textbooks or presented verbally in lectures, constitute a common experience of individuals in schools as they learn about science and thus an examination of these resources provides a foundation for discussing the competencies of these individuals in their conduct of scientific practices—such as interpreting graphs.

Purpose

In this study, we investigate the use of inscriptions in different scientific texts and the interpretive practices of individuals presented with an inscription drawn from those texts. The present study was conducted to begin formulating answers to the question, “Why do students find it so difficult to interpret scientific inscriptions?” We began our investigation by seeking answers to the two corollary questions, “What are the text-based inscriptions available to readers of science texts at different educational levels?” and “What are the interpretive practices that individuals bring to interpreting some of these inscription resources?” In other words, we wanted to know whether the graphical representations that appeared in the texts allow students to engage in trajectories that lead them to the scientific interpretation practices from which these representations arise.

Research Design

This study is situated within our research program that is concerned with the social, demonstrable, and naturally accountable aspects of scientific research, representation, and interpretation practices. In this, we draw on studies of the semiotics of scientific texts (Bastide, 1990; Lemke, 1998) and the ethnomethodology of mathematical representations (Livingston, 1986; Lynch, 1990). Our studies of interpretive practices are informed by the methods used in anthropological investigations of scientists working with graphical representations (Suchman & Trigg, 1993; Woolgar, 1990) and methods of interaction analysis (Jordan & Henderson, 1995). Our analysis of interviews are based on the assumption that when participants are presenting their arguments in a public forum their reasoning is observable in their socially structured and embodied activity (Garfinkel, 1991; Heidegger, 1977).

We focused our analysis on the biological sub-domain of ecology for five main reasons: (i) the different interpretive domains of the authors based on their prior research experiences (GMB ecology; WMR physics) meant that they could ‘play out’ tensions between newcomer/old-timer differences in interpretation to deepen their understanding of both the text materials and the interview transcripts thus assisting in the process of progressive subjectivity (Guba & Lincoln, 1989); (ii) individuals with an ecology background are well represented in our database of over fifty individuals with whom we had conducted interpretive interviews around graphs (fifteen of whom were professional scientists with a minimum of an MSc and 6 years of experience conducting independent research); (iii) our prior research in the representation practices of Grade 8 students engaged in ecological field work (Roth, 1996; Roth & Bowen, 1993, 1994, 1995) provided us insights into the development of graphing practices in ecology; (iv) our access to the second-year ecology course lectures and seminars provided us a resource against which to contrast the content of the textbooks; and, (v) we have been working at

understanding the trajectory of experiences involved in becoming an ecologist in part by engaging in ethnographic research as field helpers for an ecology research project during which we observed use of inscriptions as part of the everyday scientific research. We examined the text resources available to ecology students and videorecorded post-B.Sc. individuals as they interpreted graphs. In this way, we attempted to better understand the progress of individuals along the trajectory towards becoming competent users of inscriptions in the conduct of science work.

Texts and their Analysis

We examined various textual resources available to students and professional researchers. Given that lectures in science classes draw on textbooks and journal articles for inscriptions to use as a foundation for discussions (and that textbooks often use inscriptions copied or modified from those in journals) we used as sources high school textbooks, university level ecology textbooks, and professional scientific ecology journals.

We began our selection of biology textbooks with those that are exclusively used in several surrounding school districts. We added two other Canadian textbooks to these textbooks and complemented this selection with two popular American textbooks from the Biological Sciences Curriculum Studies series. In this way, our selection included three of the four most representative biology textbooks (Moody, 1996). These textbooks included *Biology: Living Systems* (Oram, 1983), *Discovering Biological Science* (Andrews, Andrews, Balconi, & Purcell, 1983), *Inquiry into Life* (Mader, 1985), *Biology* (Craeger, Jantzen, & Mariner, 1985) *Biological Sciences: A Molecular Approach* (Biological Sciences Curriculum Study, 1985) *Biological Sciences: An Ecological Approach* (Biological Sciences Curriculum Study, 1987). For comparative analysis with the college ecology textbooks and journals we identified those chapters related to ecology and enumerated the totals of the different inscriptions in those chapters.

Our selection of college-level ecology textbooks began with a review of those promoted by publishers at a recent international biology conference held at a local university. We then established a list of textbooks used in the teaching of second year ecology courses at local universities and, combined with the publisher recommendations, collected four of the ecology textbooks which represent the major textbooks used to teach second to fourth year ecology courses at North American post-secondary institutions. This list was composed of *Ecology: The Experimental Analysis of Distribution and Abundance* (Krebs, 1994), *Elements of Ecology* (Smith & Smith, 1998), *Ecology: Individuals, Populations, and Communities* (Begon, Harper, & Townsend, 1996), and *The Economy of Nature: A Textbook in Basic Ecology* (Ricklefs, 1993). For each book we counted the different types of inscriptions in the entire volume. The references to the figures in the main body of the text and the use of captions were sampled in one-third of each textbook.

To allow comparisons between inscriptions in textbooks and those used in professional science work, we selected ten prominent scientific journals used in the B.Sc. program of Resource and Environmental Management at a Canadian university. After a preliminary analysis, we selected five to be included in this study because they represented a broad range of foci: applied research, pure research, and modeling ecological processes. Both formal (citation indices) and informal (biology professors) indicators suggested to us that our selection represented highly regarded journals. The journals included *Journal of Animal Ecology*, *American Naturalist*, *Ecological Monographs*, *Ecological Applications*, and *Entomology*. For each journal we sampled the entire 1995 volume, unless it was longer than 500 pages in which case we sampled the number of articles to bring us above the first 500 pages of the volume.

We began our analyses based on a category scheme for the analysis of inscriptions. Based on this scheme, we independently analyzed and counted all inscriptions used by three ecology chapters in one high school biology textbook; we also analyzed several

articles from various ecology journals. During our first meetings, it became clear that our initial category scheme needed refinement, especially that of “graphs.” In joint sessions, and based on those graphs that we had seen, we refined our scheme to differentiate between scatter plots, scatter plots with points connected, scatter plots with best fits, scatter plots with graphical models, and graphical models. This categorical determination was then applied to the analysis of the three different sources of inscriptions we were examining.

Apart from the frequency of the different types of inscriptions, other aspects of their inclusion in the scientific texts were also examined. Captions were examined to determine the role they might play in providing information to the reader. We made note of whether the captions were just a title, described the content of the inscription, provided additional information or detail that might assist in interpreting the inscription, or provided an interpretation of the inscription. We also examined how the inscription was referred to in the main body of the text noting whether it was just referred to in the text (or not referred to at all), had additional detail provided, or whether an interpretation of the inscription was provided in the main text.

Interviews and their Analysis

To understand the interpretive practices enacted by students and practicing scientists we interviewed over fifty individuals (including fifteen scientists) and asked them to interpret different graphical inscriptions. In these interviews, the participants were videotaped as they, either individually or in small groups, discussed how they would interpret different inscriptions (representative of different graphical inscriptions found in the textbooks).

In this paper our analyses focus on the interpretation of an inscription by four graduates from a BSc program. This graph was one of several inscriptions for which they provided an interpretive reading of several inscriptions (or the caption or problem stem associated with them) during interviews. These graduates had all completed a bachelor’s degree but had not subsequently engaged in conducting research of their own or graduate work,

although all had worked as assistants or technicians on research projects of others. We contrast their interpretations with those of experienced researchers who have conducted their own research projects. Members of this group have, at a minimum, an MSc degree and six years experience conducting research projects.

Transcripts of interviews were made in an on-going fashion as the interviews progressed. All records were subjected to an interpretive text analysis grounded in semiotics (Bastide, 1990) and hermeneutics (Ricoeur, 1991) of scientific texts. We independently conducted interpretive analysis of the data (viewing videotapes and reading transcripts) to establish tentative interpretations which were framed as assertions. We then collectively conducted interaction analysis (Jordan & Henderson, 1995). In this work we examined our tentative assertions by reviewing other videotapes to find other episodes supporting or disconfirming these assertions which thus led to new or reformulated assertions. Through repeated cycles of interacting with each other and independent analysis, we identified dis/confirming evidence for our tentative interpretations leading to further refinements of our claims. The understandings discussed here emerged from these iterations.

In our database of transcripts of inscription interpretations are discussions of several different types of graphs. Previously, we demonstrated that BSc graduates experience difficulty with a task which, to be successfully conducted, required transforming paired-data on a map into a scatter plot onto which a line of best-fit could be mapped (Roth, McGinn, & Bowen, 1998). An analysis of second year science students' interpretation of a graphical ecological model demonstrated that difficulties arose in part from their lack of experiential resources (Bowen, Roth, & McGinn, in press). In the present report we examine the interpretations BSc graduates produced relating to a scatter plot with connected data points (Figure 1). Apart from the availability of the interpretive transcripts for this graph, we chose this representation for several other reasons: (i) a version of it appears in a

university ecology textbook; (ii) the graph appeared in the lecture component of a second-year ecology course; (iii) we identified the original graph in a scientific publication; and, (iv) graphs of this type are the most frequent graphical inscription in journals and college ecology textbooks. As part of our analysis we contrast the version of this graph used in lecture and textbooks with the version which appeared in the original scientific publication. The caption provided on the version of the graph used in the interviews is based on that used by the professor in second year ecology course lecture which is similar, both conceptually and in word use and length, to that appearing with this type of graphical inscription in textbooks. As well, to replace any context provided by the body of the main text in textbooks, a brief verbal introduction was provided by the researcher in the interviews based on those made by the lecturer as he introduced the graph to his class. This introduction was also styled similarly to how the main text in textbooks referred to inscriptions of this type.

[Insert Figure 1 about here]

Analysis

The following analyses focus on different aspects of inscriptions and their use by students. A statistical analysis compares the frequency of different types of inscriptions in the different resources. A subsequent semiotic analysis of the common inscriptions found in the different resources is contrasted with an examination of the co-embeddedness of texts and inscriptions. An inscription used in both lectures and textbooks was compared with its' original journal article usage and then draws on interpretations of the lecture/textbook version of the inscription by college graduates to reveal what aspects of the inscription they have difficulties interpreting, and how those breakdowns are related to its transformation from journal to textbook inscription.

Statistical Analyses

Recent reform documents in science and mathematics education (e.g., NCTM, 1989) suggest adopting a framework which provides for students to engage in “authentic” scientific experiences. This would suggest that, to some degree, students should engage in practices congruent with those of scientists and experience the same types of graphical resources as those found in the work of scientists. Given this framing, we begin our analysis with a discussion of the frequency of use of the different types of inscriptions in the three different resources.

Inscriptions are frequent in all three types of writing. On average, 1.38 per page in high school textbooks, 1.75 per page in college textbooks, and 1.46 per page in scientific journal articles. However, there are considerable differences in which type of inscription was predominant in each resource (Figure 2). Statistical analysis shows that the college-level textbooks include significantly more inscriptions than did the journal articles or high school textbooks ($F(2,N) = 4.74, p < 0.05$). Our posthoc test (Duncan’s multiple range test) indicates that the number of representations per page in journal articles and high school textbooks are not different, but that college texts have significantly more inscriptions per page than either of the other two sources. The differences between the ecology journals and textbooks are immediately obvious (Figure 2). Both high school and college ecology textbooks strongly emphasize photographs, drawings and diagrams as well as graphical models. These are considerably less frequent in journal articles. Journal articles emphasize equations and tables with statistics more so than do high school or college ecology textbooks. A statistical test indicates that an equi-distribution model had to be rejected ($\chi^2(18) = 2148, p < .0001$).

[Insert Figure 2 about here]

Semiotic Analyses

The importance of the differences in types of inscriptions across resources becomes salient in the following semiotic analyses. Textbooks emphasize photographs, diagrams, and naturalistic drawings to a much greater extent than do journal articles. These types of inscriptions generally convey little conceptual information lacking the capability of higher order inscriptions (such as scatter plots) to depict correlations between co-varying factors. In addition, the inscriptions in textbooks are generally decontextualized and far removed from direct phenomenal experience. For example, to illustrate a process of ecological *change* it is not unusual for textbooks to offer a *single* photograph. However, to see a change, the reader has to read a lot of personal experience into the photograph. One of the textbook pictures we discussed depicts a plowed field in the foreground with a small stand of trees several hundred meters off to the left and a line of houses in a subdivision along the edge of the grass border of the plowed field. The caption reads “Housing is increasingly encroaching on arable land.” This caption provides few insights into the process of *encroaching*, assumes that the reader understands the meaning of “encroaching,” and offers few cues as to what parts of the photograph the reader should attend to so as to infer the process. The caption describes a *process* although the picture depicts a *static* scene. Together, picture and caption present a considerable interpretive challenge. This is for several reasons. The picture and caption are both experience-distant for members of modern urban society. In addition, the process of encroachment occurs over wide areas over extended periods of time, not as represented in the small field of view proffered in the photograph.

Adding to the interpretive complexity, the word “encroachment” is not value neutral but has embedded within it a judgment of most appropriate land use. In this instance the interpretive stances of different individuals involved in “encroachment” are removed from the presentation—the viewpoint of ecologists concerned about encroachment of urban areas

on crop land undoubtedly differ from the farmers who benefit financially from land speculators and the construction contractors who build the homes. In addition, use of the term “encroachment” ignores that in the process of turning the field into farmland in the first place we enacted a dramatic change in the ecology of the area. The turning of the crop land into urban roads is arguably of no more ecological concern than was the original conversion from prairie, marshland or wood lot into farms in the first place.

Naturalistic drawings in high school and university textbooks are also experience-distant. As a result, they are difficult to read. Non-specialists are required to “trust” the depiction as rendered by the artist—few students have the relevant lived experiences to bring as interpretive resources to specific diagrams. For the most part, these drawings show mono-tonal sketches of plants, animals, or other organisms. A scale of reference is often absent and the drawings depict parts of the organisms. These diagrams are provided as contextual aids to understand the text. The same types of naturalistic drawings are found in more than one of the textbooks. For instance, sketches of “Darwin’s Finches” appeared in several textbooks (see Figure 3 for our own representative example). These sketches depict several bird heads side by side of approximately the same size and a surface reading may (mis)lead the non-initiate reader to the conclusion that the beaks are of a comparable size. Darwin’s finches varied in body and head size as well as beak shape and size, so that comparisons about niche partitioning using the diagrams is impoverished. The non-initiate reader takes from those sketches that there are birds with beaks, which look different, and they eat different things—which dramatically under-represents the ecological principles which underlie arguments made about and from the example of “Darwin’s finches.”

[Insert Figure 3 about here]

Scatter plots and histograms occur infrequently in high school textbooks compared to university textbooks and journal articles and they are also used differently in the high school texts. University textbooks and journal articles frequently deploy graphs in clusters

containing two to six graphs. This allows readers to interrogate the graphs by moving back and forth between them with understanding arising from the readers' interpretive engagement between the different graphs. Thus, whereas in the high school textbooks meaning is assumed to be recoverable from a single graph, university textbooks rely more on the contrast between several graphs.

Co-Embeddedness of Inscriptions and Texts

Part of the interpretive difficulties related to graphs in high school textbooks arise because the design and structure of inscriptions assume much knowledge about context, distributions, and variability, and how these are represented graphically. Graph use in high school textbooks lies in contrast to how scientists (in journal articles) use graphs in direct combination with the textual resources within which they are embedded. In journal articles captions are frequently extensive—often running to over 100 words—and an interpretation of the graph, often using several paragraphs of text, is provided in the main text so that the readers' understanding arising from the graph and text is specifically directed (Roth, Bowen, & McGinn, in press).

Our research shows that there is less guidance in the university ecology textbooks and, ironically, even less in high school textbooks. In university ecology textbooks captions are often as long as four dozen words (containing both elaboration and interpretation) and there are usually several sentences which provide either further details or interpretation of the inscription found in the main text. In one college textbook the caption for the figure of finches (depicting heads of birds from different islands) consists of 34 words and accomplishes two tasks: (i) it notes that the sketches of heads are divided into two groups, from two different islands, and (ii) that there are differences in beak length and depth in the two different groups. The reference in the main text for the figure is on a previous page and the paragraph which provides the conceptual embeddedness started two pages earlier. The relevant paragraph is seventeen lines (~170 words) long and, in its first half, introduces the

concepts of adaptive radiation and speciation and related those to remoteness of islands or archipelagos. In mid-paragraph there is reference to the diagram as an example of the “best known” occurrence of this. The relevant historical period when those groups first evolved is identified in addition to the origins of the group(s). The final sentence describes how distribution and specialization occurred through competition and exploitation of a variety of features in the environment.

In high school textbooks, captions are much shorter, less than one dozen words. The text provides little interpretation of the inscription—in some instances, the main texts do not even reference the graphs. High school textbooks do not often provide interpretations of the inscriptions and captions are no more complex for graphs than those provided for photographs and tables. In one high school textbook, the text relating to Darwin’s finches is embedded in a narrative about Darwin’s visit to and data collection on the Galapagos Islands; a photograph of one of Darwin’s finches accompanies this text. This photograph shows a dark-tan bird perched on a branch; the foreground and background are out-of-focus and provide little context. The caption consists of a 20-word sentence and the main text refers to the diagram in two sentences in one paragraph. In a second paragraph the birds are referred to repeatedly in the course of a narrative that describes how Darwin came to notice the differences between the birds and contemplated if islands had endemic species. The text suggests that Darwin had the finches examined by bird experts many years later and then related questions for which Darwin did not have answers for the following twenty years. The chapter continued with the development of his ideas about descent with modification and natural selection, but did not return to either the differences between the finches or the significance of the distribution on different islands.

Differences between caption length for the textbooks from college and high school ecology is consistent with trends noted between journal articles and the high school textbooks with the college textbooks falling between the caption lengths of those two

resources. Our example above from a high school text is unusual in that the content of the figure is referred to so frequently in the main text, therefore constituting a negative case. However, it is consistent with the use of figures as found in the main text of high school textbooks in that they are usually not explicitly connected to broader conceptual claims. High school students (college students to a lesser degree) thus have considerable interpretive latitude. This is in contrast with journal articles in which the main text and captions are constructed to severely limit interpretations (Bastide, 1990).

Transformations in Scientific Representations for Educative Use

The structure of graphs, their axes, and captions, frequently differ between those used in the textbooks and those used in ecology journals. We wondered if scientific graphs used in textbooks would differ from the original source and how these differences might inform our analysis. For this task we re-drew a version of a graph used in a second year university ecology class lecture already adapted from a textbook. This graph is used to show how differences in plant physiology can be related to plant distribution. We obtained a copy of the original graph and caption by obtaining the original journal publication.

[Insert Figure 4 about here]

An inspection of the two graphs reveals five major transformations as the original graph (Figure 4) was adapted for instructional use (Figure 1). First, the curves are substantially smoothed. Secondly, whereas the original graph shows data points joined by a line, the graph in the textbook only plots trend lines without the variations. Thirdly, the y-axis label is considerably altered. In the original graph the CAM and C3 lines is on the same scale and is referenced to the y-axis numbered from 0 to 90 in increments of 10. The value at each sampling station for the CAM and C3 lines totals to one hundred. The measured samples from which the C4 line was drawn are determined differently and represented “percent cover.” In being transformed to an educational inscription, these different scales and units are melded into the scale “relative importance” and the density of plants with all three

physiological conditions are depicted on a single scale. Fourth, a grid is added to the “background” of the graph. Finally, the educational graph adds an upper x-axis label which implies a positive correlation between elevation and moisture level and a negative one between elevation and temperature.

Apart from changes to the structure of the graph, the caption is also different. The new caption contains 71 words and references in the main text are substantially reduced—from the methods and data section of about 2.5 pages to two paragraphs in the book. The caption of the original graph refers the reader back to the original text. The reader is thus sent from the main text, to the figure, and then explicitly back to a descriptive feature in the main text, thus supporting Bastide’s contention that readers of scientific texts are given little choice what they are to interpret (Bastide, 1990).

Analysis of Interviews with Science Graduates

Our analysis of participants’ interviews suggests that the problems encountered by our participants (with BSc degrees) are brought about by the very features that had been changed for educational purposes. Three of the four science graduates who interpreted this graph experienced substantial difficulty grounding their understanding of the label “relative importance” such that they could easily proceed with an interpretation of the graph. To illustrate this we provide excerpts of Rogers transcript as he interpreted the graph:

[Rogers:] and then this axis is kind of strange, relative importance, where to me importance is already a relative term. . . But you could argue that relative importance, relative importance, is that a measure of incidence? OK, what I’m asking myself right now is how do they define relative importance and, if I think of it in terms of importance of a photosynthetic mechanism, is the one that makes the best sense if you’re a plant and you’re depending on that particular photosynthetic mechanism and it works best under a given set of conditions that would be the importance to you as a plant to have that photosynthetic mechanism as compared to

any other one. . . . So, what I'm noticing is in that trend the relative importance makes sense or is linear or is directly correlated to the elevation, the gradient in temperature and moisture from say 950 meters upwards or as it has the opposite trend prior to that which has me a little bit puzzled in terms of the raise, an importance assigned to having that C3 mechanism which seems to work well for a plant at about 550 meters of elevation and in a pretty hot and dry region.

Ultimately, Rogers began relating the variations in "Relative Importance" to the differences in altitude for the three different physiology types and ceased to dwell on what the term meant. However, his analysis continues based on an interpretation of the term which meant that at different elevations, within a particular species, which mechanism was in operation varied. To further examine Rogers analysis, the interviewer commented that he did not think that plants could switch, that a species had one mechanism or another. In response, Rogers re-stated his original interpretation of a change occurring, and then suggested that if they did not switch back and forth then the incidences of different species must switch. He indicated at which elevations the "relative importance of CAM peaks out here, the relative importance of C4 peaks out here at whatever, 1450 roughly, and C3 appears to keep escalating all the way up to the last measured point." In his use of the term "adapted" in his discussion, he utilized it to mean that individual plants were well suited with the mechanism they were using to a particular elevation (and that this could vary within the species), not that the different species themselves had adapted to best survive in specific conditions (the interpretation provided by experienced researchers).

Two of the science graduates experienced such difficulty with components of the graph that it greatly hindered their interpretation and they were unable to proceed. We use segments of the transcript of Casey's interview to illustrate the considerable difficulties he had making sense of the term "relative importance" and how that ultimately meant that to him the graph had little meaning:

[Casey:] relative importance of the pathway I assume, or relative importance, wait a second (pause), OK, there's the, that's, these are the different pathways at 500, OK let's go to look at a thousand, relative importance of the C4 is low here, medium here and high here. . . . I wouldn't name this relative importance, I don't know, it's probably the proper terminology. . . . I am actually puzzled, relative importance, is that referring to these, that's, they are more likely to be found here or that's the most important pieces for that ecosystem to survive, or that area to survive, or, like here, if I'm at a thousand meters, the relative importance of, this is the C4, what, I don't know, that's, say 20, and then of, let's see, that's a C3, would be about 38, 39, or somewhere in that range I don't know, and the CAM would be sitting in about 60 something, hum, let's see, was at 20, 60, 80, 30, no, no that doesn't make much sense.

Casey had considerable difficulty proceeding with his interpretation as he was "stuck" in his interpretation at making sense of the term "relative importance." He began to examine the scale used for the axis and when he asked what it meant and was told "relative frequency." He challenged this by pointing out that the sum of the values for the three lines at a particular elevation did not sum to one hundred. He then proceeded to sum the three points corresponding to each line at several elevations to see if they were working on a base other than one hundred and was quite puzzled that they did not.

[Casey:] Then I would have to say, I don't really understand what relative importance is 'cause I can't figure out how this frequency thing works. . . . I don't know what else to say, I don't know what that means, based on what I can see, I can give you numbers [of what relative importance occurs at which elevation], I just can't tell you what they mean necessarily. I can tell you, at this elevation it's supposed to be hotter and drier and at this elevation it's supposed to be cooler and least dry and I can tell you where these things are gonna be, I just don't know what

that means. . . . If I saw it and I looked at it, as I said, I can give you a number, but if you told me go find the relative importance of this 100 meters for a C4 plant, I could tell you what it would be, I just couldn't tell you what relative importance meant or anything like that, so frankly it's, for me, it would be a non-event.

Because Casey could not link "relative importance" into his web of familiar experiences, he was unable to provide what he considered to be a satisfactory interpretation. He could discuss the graph in the abstract. He used the mathematical tools with which he was familiar to try and make sense of "relative importance" in terms of frequency, but understood how using it as such a referent had implications for the structure of the graph and the relation of the lines to each other. Because he could not find a common base to the summed values at different elevations, he rejected the suggestion that "relative importance" stood for frequency of the different plants.

Our analysis of interpretations provided by other participants revealed similar difficulties, including aspects of the construction such as the label on the upper axis which suggests that temperature and moisture co-vary with elevation. Overall, three of these four participants had difficulty providing an interpretation, in part because of the label "relative importance" and the lack of explanation available to them. Even when that explanation was provided, it was not sufficient to proceed.

There were several differences between the interpretations provided by the participants with BSc degrees and those provided by professional scientists. Most notably was the lack of references external to the graph. In earlier research, this was also typical of interpretations provided for graphical models (Bowen, Roth, & McGinn, in press). It was also commonly found in interpretations of this graph with the exception of Rogers who made sense of the co-varying of temperature and moisture with elevation by relating it to his travels in Kenya up a mountain. For the most part, interpretations of the graph centered around specific elements of the graph itself and not any external references; that is, the

graph was referentially isolated from the participants' other experiences (e.g., Greeno, 1988). In addition, interpretations focused on the patterns of individual lines not the relations between the lines. Finally, participants found it difficult to draw implications of these distributions for the adaptiveness of species to these climatic regimes or to relate the graph to natural selection.

This was in striking contrast to the interpretations provided by practicing scientists as they worked at making sense of this inscription. Most scientists who read the graphical representation did three dimensions of reading work. First, they read the lines in terms of their past experiences relating to a changing fauna with elevation and associated climatic changes. At the same time, they locate the three distributions with respect to each other. Finally, they attempted to explain the location of the three maxima in respect to each other by drawing on the concept of adaptation of plants to the physical environments. Their analytic work carved the graph such that each of the three relations told a story about the relative frequency of a type of plant (even if they did not know what type of plant it might be). The other dimension of their work was the relation of the text to some state in the world (ecological systems, or other graphs). First, this state is about the relationship between the frequency of one type of plant with changing elevation (or climate). In the second instance, the state has to do with the existence of ecological niches. Their interpretations often followed a complex trajectory as they cycled between references to the caption, the graph, and their experiences in the world to make sense of the components of the graph as they proceeded in their interpretation. This reflexive dialectic was much less evident in the present participants (BSc) as they remained "within" the graph making few references to components of the world external to the graph.

Discussion

The increase in complexity in inscriptions in textual resources used to teach science at increasing educational levels is not paralleled by an increase in interpretive competencies of

those who are using those resources as they progress through the educational system. As we noted in other studies, differences in constructing consistent and detailed interpretations of graphs were not so much due to differences in interpretation “skills” than to the extent of the (personal or vicarious) experiences of the natural world that individuals use as counterparts to the graphical representations. Thus, for example, whereas scientists used their extensive experiences with several natural populations to interpret plant distributions in a dialectic process from graph to population, even college students had few such experiences that would help them to make sense of the graph (e.g., Roth & Bowen, 1999). On the other hand, we observed tremendous data and graph interpretation competencies among Grade 8 students who had extensive experience in field research and who used this situated knowledge to elaborate the meaning of graphical representations.

We conclude that graphical representations in scientific texts are easier to interpret and less ambiguous than those which appear in high school or college texts. High school textbooks generally emphasize photographs and diagrammatic resources. This raises issues regarding how effectively these texts can be used to facilitate student learning about the inscriptional and interpretive practices of “authentic” science such as is called for in various reform documents. Similarly to our past findings with journal articles, inscriptions in college textbooks are embedded in the overall text with interpretations of the inscriptions usually provided in either the caption or the main text, unlike in high school textbooks which did not usually provide such an interpretive framework for the reader. Thus, the trajectory of interpretation competencies is not paralleled or supported by the materials generally available to individuals. High school and university students have tremendous difficulties interpreting graphs, but given the experiential resources on which they can draw (something schools generally do little to help them develop) to make sense of the components of the graph and the patterns between variables, this is hardly surprising. In contrast to the cognitive deficit models often proposed to account for their poor success

with these types of interpretive activities (e.g., Berg & Smith, 1994), we instead suggest that their difficulties lie in having had few experiences at conducting, interpreting and defending research themselves—for engaging in such activities developed considerable competencies with inscriptions in Grade 8 students. Earlier work among Grade 8 students (Roth & Bowen, 1994, 1995) documented their development in framing field studies and constructing their arguments through the use of various types of inscriptions. It is through their engagement in their own research from which they constructed arguments to convince others in their scientific community that their extraordinary competencies in the use and interpretations of inscriptions developed.

It is also notable that the very changes made to graphs published in journals to include them in textbooks contribute to the interpretive difficulties encountered by those for whom they were intended. Our observation in textbooks and anecdotal reports from publishers suggest that such changes are done with little understanding of the consequences of the decontextualization for student understanding. Cartesian graphs in textbooks usually portray “clean” lines which suggest unique and unambiguous relationships between the variables portrayed. Our research suggests that this re-affirms and develops the belief in students that there is an underlying mathematical structure to nature such that an unambiguous mapping of {Fundamental Structure $\longleftrightarrow$ Mathematical Form} can be made (Lynch, 1991). The inclusion (and modification) of inscriptions in science textbooks does not appear to be informed by an understanding of their use to either students or within the scientific community. In the interpretation of Figure 1 by other participants, this “cleaning” may have resulted in interpretive difficulties arising from the contradiction between the depicted relationship (found on the left hand side where the CAM & C3 lines cross) and the caption which supports it—which might otherwise have been attributed to variation in sampling (given the non-smooth nature of the original data plots) or other features not evident in the graph.

To make our argument more clear, we provide a changed graph as it might be used in textbooks (Figure 5). This graph includes the kind of information that our research shows is necessary in order to help newcomers to ecology and graphing link representations to other things that they are familiar with. For example, rather than using the distinction “hottest/driest $\longleftrightarrow$ coolest/least dry” the distinction now includes the more familiar “wettest” as the second pole. The paired correlation (e.g., hot/dry) was problematic for many students who interpreted the graph so it was simplified to a single variable; moisture level (the educational intent of the graph is to demonstrate plant distributions which are climatologically influenced—which using a single co-variable is consistent with). In addition, data points have been added to allow students to assist students in differentiating between graph models and graphs depicting empirical data. Furthermore, rather than just specifying the labels C3 and C4 for the photosynthetic mechanisms, examples are provided. That C3 and CAM plant distributions are measured in a different way than C4 plant distributions is also made explicit and detailed readings are provided for the three data lines. Finally, the “lesson” that can be drawn from such graph is stated explicitly in the caption—that the graph can be used to show differential adaptation of plants to climate.

[Insert Figure 5 about here]

Educational Significance

The increase in complexity of inscriptional resources (such as textbooks and, later in a science degree program, journal articles) is not paralleled by a notable increase in interpretive competencies. In another analysis we contrasted the interpretive practices of science graduates with second year ecology students and fourth year education students and found few differences (Bowen & Roth, 1999). This suggests that it is not the exposure to more complex inscriptions in textbooks (or lectures) which leads to the development of competency in interpreting these resources and that it is insufficient to “tell” students (in lectures or textbooks) how or where to use particular inscriptions or how to interpret them.

Students need to develop competency in the inscription practices of science by engaging in activities during which inscriptions are something “everybody uses” to convince others of the utility and accuracy of their arguments. Effectively using graphical representations to construct scientific claims is an important component of the proposed curriculum reforms that deal with inquiry-based teaching, and evidence from this study suggests that competency in interpretive practices does not derive from programs which “expose” students to increasing complexities of inscriptions in their textbooks. We suggest that to effectively learn to use and interpret inscriptions, whether in an undergraduate education or a science program, students need to participate in long term, independent-inquiry project-oriented courses with peer review and critique—an approach which addresses both content and process issues of their science backgrounds.

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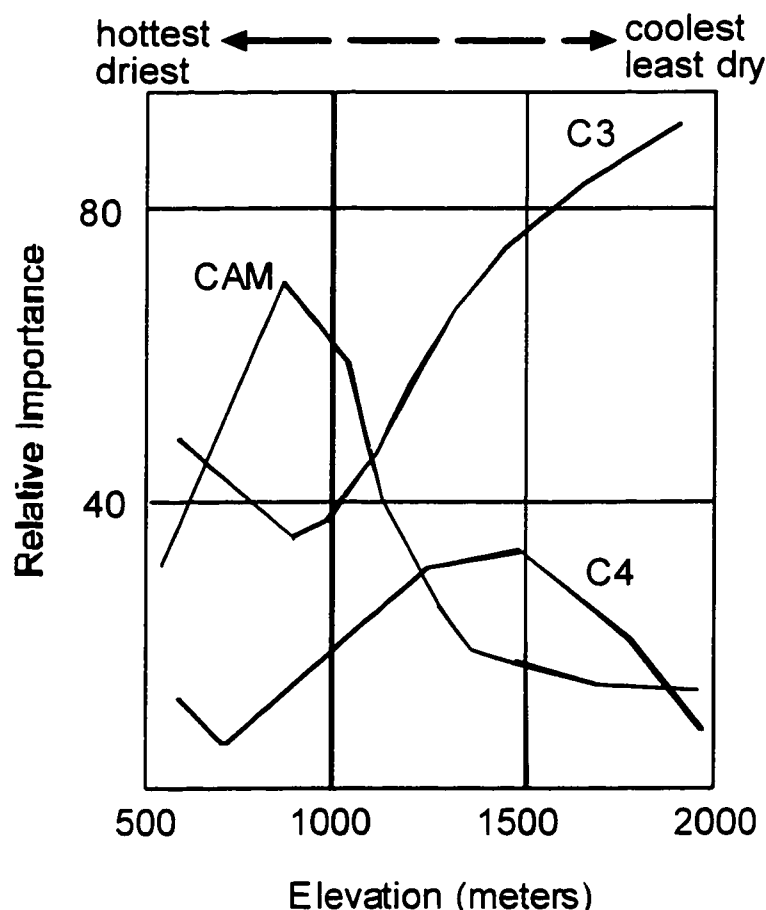
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Distribution of C3, C4, and CAM (succulent plants) in the desert and semi-desert vegetation of Big Bend National Park, Texas, along a moisture and temperature gradient due to differences in elevation. CAM plants with nocturnal gas exchange for water conservation predominate in the hottest, driest environment, C4 plants are maximally important under intermediate temperature and moisture conditions, and C3 plants predominate at the cooler, least dry end of the gradient. (Modified data from Eickmeier, 1978)

Figure 1. Plant Distributions graph and caption provided in its use in a university ecology course.

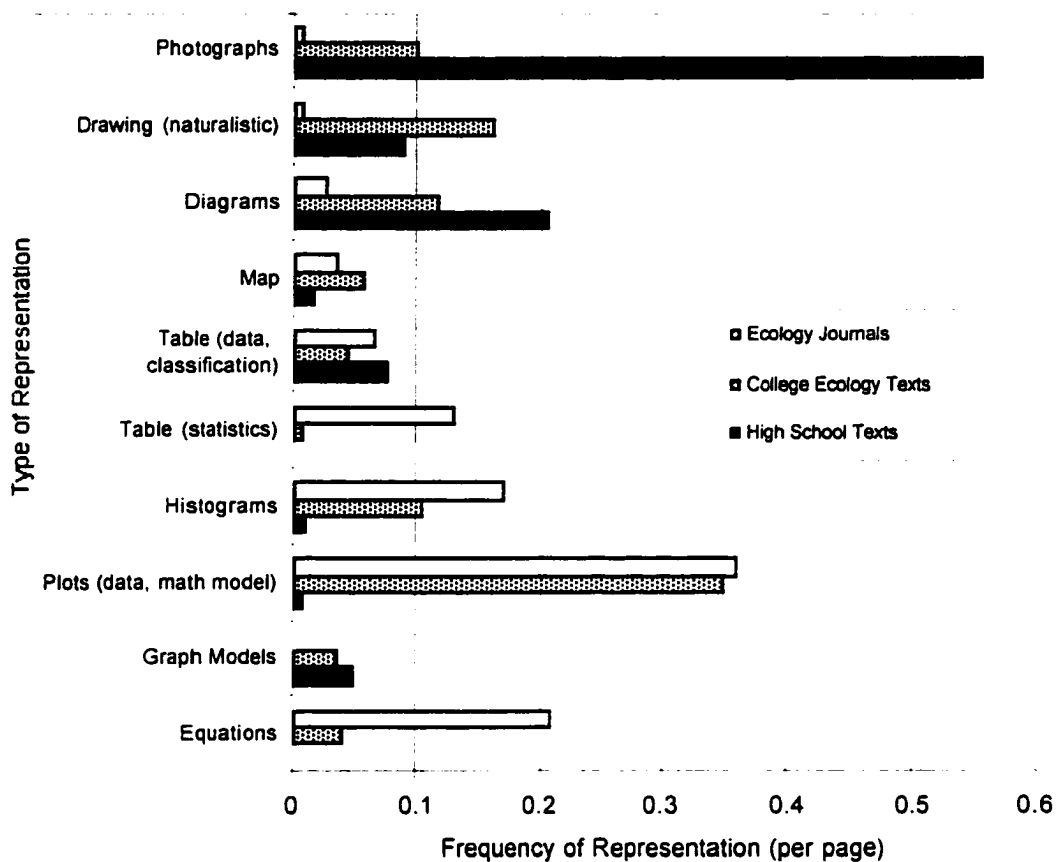
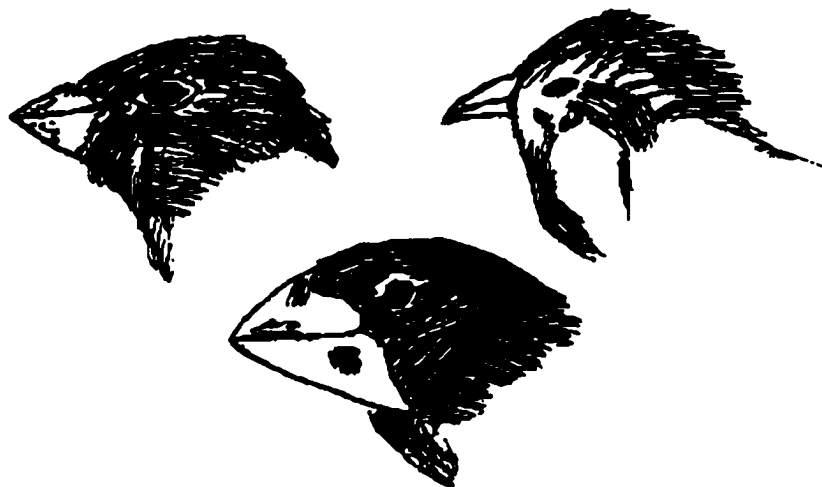
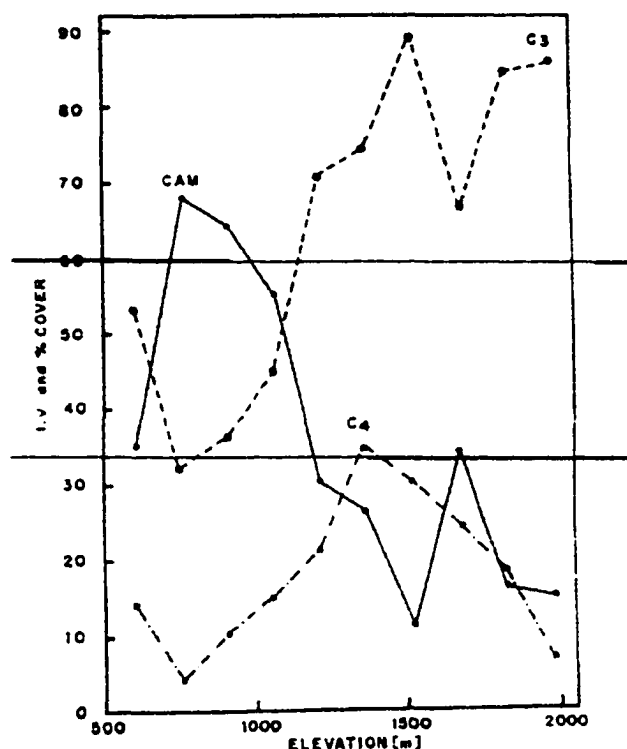


Figure 2. Frequency of inscriptions found in high school biology textbooks, university ecology textbooks, and ecology journals.



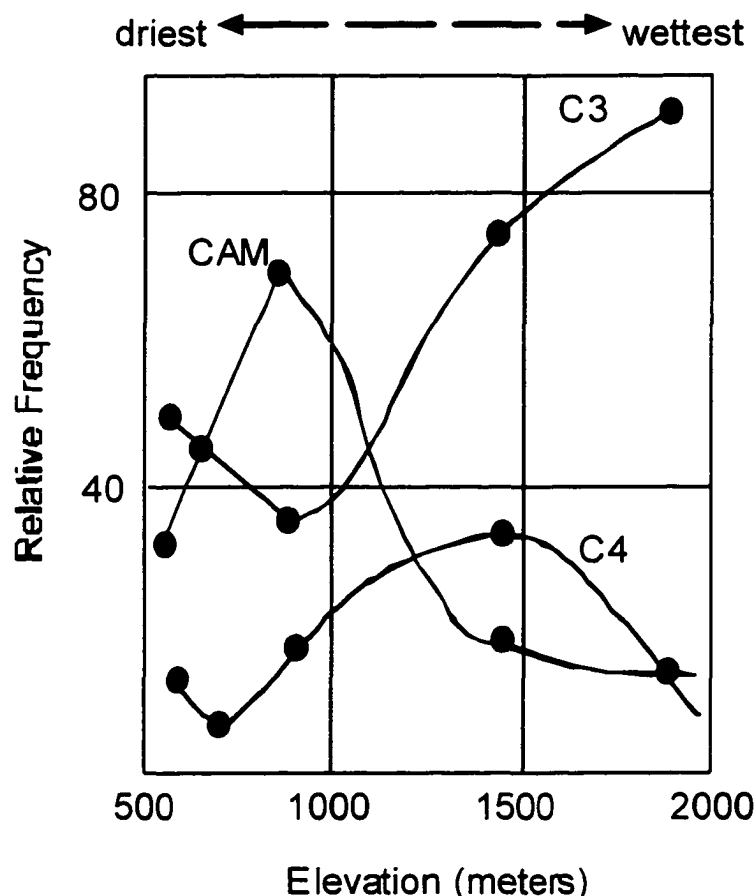
Example Caption: Sketches of heads of Darwin's finches from the Galapagos Islands illustrating the ranges in beak depth and length from different islands.

Figure 3. Example of types of illustrations of Darwin's finches and associated captions in textbooks.



(Original Caption) Distributional pattern of photosynthetic pathways along an elevational gradient in Big Bend National Park, Texas. Lines for CAM and C3 pathways are plotted for species importance values (see text for description) lumped by pathway at each sample elevation. The C4 pathway is almost exclusively represented by grasses for which only cover data were taken; therefore, the line for the C4 pathway is based on per cent cover of grasses at each sample elevation. (from Eickmeier, 1978; used with permission)

Figure 4. Scan of the original source material which was modified to provide a resource for students in ecology lectures and textbooks.



Distribution of plants with three types of photosynthesis, C3 (e.g., some shrubs and herbs), C4 (e.g., grasses), and CAM (e.g., cactuses) in the desert and semi-desert areas of Big Bend National Park, Texas. C3 and CAM are on the same scale and their relative frequencies sum to 100. C4 plants are measured on a different scale. The climate changes as elevations change—at higher elevations moisture increases (the climate gets wetter), and the different plant distributions suggests that the three types of plants have adapted to specific conditions. CAM plants exchange gases during nighttime to conserve water and predominate in the driest (and hottest) environment. C4 plants are most frequently found where temperature and moisture conditions are at intermediate levels. C3 plants maximally occur in wetter (and cooler) climates found at higher elevations. (Modified data from Eickmeier, 1978)

Figure 5. Proposed changes to the graph for use in ecology textbooks.

Chapter 7:

Reductionism in biology courses: Fables of the reconstruction

Reductionism in biology lectures: Fables of the reconstruction

Abstract

Enculturation into scientific practices occurs in overt ways when students learn the standard practices of domain including discourse, representation use, and deployment of instrumentation. However, Bourdieu (1997) alerted us to the fact that most aspects of enculturation pass unnoticed. In this article, we show how a particular factual way of presenting graphical representations affords ecology students to adopt reductionist worldviews according to which understandings of ecological systems can be constructed from the knowledge of previously isolated variables and their measurements. We contrast evidence from a second-year university ecology course with data collected during ethnographic field work and interviews with scientists and autobiographical evidence that renders the depiction of scientific knowledge in lectures problematic.

Lectures are the main instructional experience of most university undergraduates in biology and thus warrant some careful consideration when it comes to understanding how they learn about scientific practices. Furthermore, it is reasonable to assume that in lectures students not only learn scientific facts, laws, and theories, but also about the epistemological nature of the domain to which they are being introduced. As the domain of science is characterized by a reductionist worldview, it is judicious to ask in what manner lectures contribute to the development of this worldview in students. Such a question is particularly relevant in a subject such as ecology which is purportedly about the holistic understanding of systems (Ricklefs 1990). Given the on-going public debate about human-induced environmental disasters we might question the scientific ethos of analyzing nature in terms of small numbers of isolated variables rather than the holistic approaches favored by traditional ecological knowledge and environmental activists.

The role of epistemology in teaching and learning has been of increasing interest to science educators. Researchers investigate: how teaching practices such as questioning communicate forms of knowledge and particular epistemologies (Poole 1994); how engagement in open inquiry and epistemological discussions over a two-year period influence students' epistemological commitments (Roth and Lucas 1997); or how existing epistemological commitments mediate students' approaches to problem solving (Hammer 1994). However, we know little about the more "insidious" aspects of communicating a particular epistemology that comes from enculturation to "authentic" science. If the discipline of ecology is about developing holistic understandings, then studying the educational practices of the discipline should provide a better understanding of how students are enculturated into holistic worldviews.

The purpose of this study was to investigate how particular aspects of ecology lectures given to university students—graphing and graphs—present the nature of scientific process and scientific knowledge. This article examines which scientific practices and knowledge

students are enculturated into in a lecture course through comparison with the practices of “science” observed in the everyday research practices of working scientists and graduate students and by drawing on the lead author’s autobiographical experience of becoming an ecologist.

Ecology and Reductionism

The word “ecology” is derived from the Greek word “oikos” meaning house, the immediate environment of humans, but its meaning has been expanded to include “the study of the natural environment, and of the relations of organisms to each other and to their surroundings” (Ricklefs 1990, p. 3). Thus, understanding “ecology” means to be competent in reconstructing the “larger picture” of nature from the products of reductionist science practices, such as graphs. This reconstruction emerges when individuals take their understandings of the component-parts and assemble them to form a holistic understanding of nature.

One methodological aspect of “authentic” science which is clearly related to reductionism (Longino 1990, p. 226) is the goal of understanding nature through the ensemble of simple relationships involving small numbers of variables: “to understand a particular phenomenon, one must dissect it into its components” (Ricklefs 1979, p. 8), and particular methodological aspects of scientific practice encourages and may even necessitate taking a reductionist approach in individual studies. Central to the practice of ecology, as of all science, is the construction of mathematical re-presentations—including statistics, graphs, and mathematical models—that are said to mirror nature in the relation {world $\longleftrightarrow$ mathematical structure} which has come to be known as Wilson’s couplet (Lynch 1991).

Many scientists argue, including ecologists and animal behaviorists, that it is then necessary to reconstruct holistic understandings from the “component” parts and that failure to do so can lead to a lack of understanding of ecology (Barrett, Peles, and Odum 1997) or

animal behavior (Barber 1993; Griffin 1992). That is, faced with mathematical structures in Wilson's couplet, the messiness of the natural world has to be reconstructed. In recent years, some authors have identified the reductionist tendencies of science as being partly responsible for ecological disasters such as the collapse of the Newfoundland cod stocks (Finlayson 1994). The public debate about environmental issues illustrates that there are considerable portions of modern society that also question the benefits of reductionist practices. In this, they call into question authentic science teaching as it has been promoted in the educational literature (e.g., Brown, Collins, and Duguid 1989; Roth 1995) which may involve an enculturation into a particular mode of addressing science-related problems. More so, enculturation into scientific practices that study phenomena by looking at two or three variables at a time keeping everything else constant is an enculturation into a particular worldview. That is, when students conduct experiments in which they relate pairs of variables or study Cartesian graphs in textbooks, they are also enculturated into a reductionist epistemology according to which the world operates mechanistically.

Research Design

In this paper, we examine how research practices and their products were presented to students in a second-year university course designed as an introduction to ecology. We focused particularly on the underlying epistemological assumptions as these were tied to the specific graphical representations used. Fieldwork among ecologists, formal interviews with ecologists and related professionals over and about graphical representations, and the autobiographical experiences of learning the reductionist practices as part of becoming an ecologist (Bowen) provide the context for our claims.

Our theoretical approach for studying science in schools, university, and professional practice is informed by the emergence of anthropological, ethnomethodological, and sociological studies of scientists at work (Latour and Woolgar 1986; Lynch 1985; Traweek 1988). In contrast to the more traditional work on science that saw in scientists a special

breed of people who use special skills and procedures to cull facts from nature, all of the cited studies take a common perspective of science as being a set of practices that is shared by members of specific communities. From this perspective, knowledge is not something residing exclusively in the heads of people, but to a large extent is constituted by the practices people (scientists) enact as they go about their daily business, how they justify what they do, the stories they tell, and so on.

Ethnographic Context

Our investigations about the enculturation and use of graphical representations took us into four different types of locations: a second-year university ecology course and the seminars associated with it; a research center in a remote, mountainous area of British Columbia; sites with public presentations of ecology research including departmental seminars and conferences; and the offices of ecologists and related professionals (e.g., forest researchers). In our experience, the particular ways of presenting graphical representations in this discipline both provides a particularly reductionist perspective on ecological knowledge and also may cause individuals to experience considerable difficulty in coming to understand natural systems and in conducting their own research.

The 13 week course had 45 students enrolled from a variety of science and general studies backgrounds and each week consisted of three fifty-minute lectures and three fifty-minute seminar; the latter each being attended by approximately one-third of the students. The lectures were presented by an ecology professor and a teaching assistant (doing doctoral work in genetics/ecology) conducted the seminars. The two had co-taught the course twice before and each year made refinements based on their previous experience. At the beginning of the course, students received a book-size volume of lecture notes which contained most of the overheads presented during the lectures. Overheads used in class had appended hand-written notes and were supplemented by other, specially-marked overheads with text and figures. The lectures were traditional featuring few interactions between

students and professor. Student questions were infrequent and few students elaborated on the lecture notes. Seminar topics were pre-determined and coordinated with the lectures. Each week the professor gave the teaching assistant written notes detailing the content he desired to be covered in the seminar, but the teaching assistant had considerable latitude in how he covered those topics. Seminar activities varied from week to week and included mini-lectures, group work on collaborative problems (the solutions of which were often presented to the rest of the class), “games” that provided students with opportunities to practice the use of terminology, question and answer sessions, and “story-telling” episodes during which the teaching assistant related tales from his own field work and experiences in science.

Data Sources

All lectures and seminars were videotaped and transcribed. The lecture notes and additional overheads were the foundation for lectures and were entered into the database. Other data sources included: copies of readings, all assignments and resources distributed in class, copies of the seminar quizzes, and empirical field notes on the basis of formal and informal discussions with the teaching assistant and students. To better understand students’ graph-related competencies, we conducted focus group interviews. These interviews were videotaped and transcribed and, with all artifacts produced, included in the database. Samples of exam papers and students’ notes were also included as data sources. Further data sources existed theoretical field notes of the lead author (Bowen) who observed and videotaped all lectures and seminars. These notes also had a decidedly phenomenological component, in that he used his experiences as an ecologist and his own learning as lenses to better understand the difficulties in learning and understanding ecology.

We further contextualized the analysis of the lectures by drawing on data collected from other sources. Various inscriptions drawn from the ecology course were used as the

foundation for interpretive interviews with graduate students and practicing scientists. These interviews were videotaped and transcribed in an ongoing fashion and provided additional perspectives to the interpretations of the lecturer and the students. A 6 week-long field ethnography was conducted with a graduate student and post doctoral fellow in ecology documented in extensive field notes, numerous daily digital photographs, and video- and audio-tapes. Further audiotaped interviews with other graduate students and field biologists about their field research experiences and perspectives on conducting research were conducted and entered into the data corpus. During the ethnography, the two authors used electronic mail for daily exchange of data, theoretical notes, and requests for further data collections. Finally, reflective autobiographical notes about Bowen's own experiences as a graduate student learning to use one of the inscriptions central to this paper were written at the time of its use in the ecology course and impressionistic field notes (van Maanen 1988) completed the data sources.

Data Analysis

We used an interpretive approach to the analysis of the data sources. Credibility was further established through the prolonged and intensive engagement in the field which provided the bases for thick descriptions which further informed our research questions and provided a foundation on which to build our understandings (Guba and Lincoln 1989). We also viewed and analyzed lectures in large groups, composed of other faculty and graduate students, which provided us with further occasion to question our own assumptions and the addition of further interpretations.

Using interaction analysis (Jordan & Henderson 1995), our interpretation emerged from individual and joint analysis of the multiple data sources. Incidents were reviewed as necessary so that tentative claims could be explored by both researchers. We then independently reviewed the tapes and transcripts concurrently to conduct fine-grained analysis of the approaches, examples, and explanations made by the lecturer. This textual

analysis was grounded in phenomenological hermeneutics (Ricoeur 1991) and semiotics of scientific texts (Bastide 1990). After an independent analysis of the tapes and transcripts we convened to re-examine our independent analyses. We discussed our individual interpretations, subjecting them to critique and analysis so that each could be examined against the understandings of both authors. Claims constructed from these discussions were then tested against the whole data set to evaluate fit and plausibility. Interpretations were deepened by the different academic backgrounds of the two authors (Bowen as an ecologist, Roth as a physicist) and the sharing and critiquing from these perspectives assisted in the process of progressive subjectivity (Guba & Lincoln 1989) making us more aware of our personal constructions and helping guard against our constructing non-viable interpretations.

Two Ecology-Specific Representations

As in other aspects of scientists work, graphical representations were central to the lecture and seminar topics (there were an average of 19.3 graph-type representations among the 25.5 inscriptions per lecture). Thus, in an effort to understand what it is that students learn about ecology in lectures, our micro-analysis of the lectures focused on the use of representations and the worldview embedded within their presentation about the concerns, practices and resources of the domain. To assist readers unfamiliar with the representation used in our examples we provide the following description of their derivation and interpretation.

In common usage, representations that use Cartesian x-y coordinates draw on specific interpretive resources including axis labels, numeric scales, units, legends, data points, trend lines (Roth, Bowen, & McGinn, in press). Cartesian, x-y graphs containing multiple curves are generally used to express relationships between an independent (x coordinate) and dependent (y coordinate). The two Cartesian representations in this study, isograph and population growth curves (Figure 1), differ from the types of Cartesian graphs

students generally encounter in high school and beginning university years because their interpretation requires a juxtaposition of the lines rather than an analysis of the line itself.

[INSERT FIGURE 1 ABOUT HERE]

Isographs such as the isoclines in Figure 1a resemble contour intervals on a topographic map in that the two axes are both independent variables and the change in the independent variable (height in the topographic map, effect in the isograph) has to be read by comparing adjacent lines. The third, dependent variable is much “less” visible in an isocline representation and demands considerable experience and attention.

The Cartesian representation in Figure 1b at first appears as a typical line graph. However, the interpretation of this line graph lies not in the pattern of the individual lines but instead in the juxtaposition between the lines. The vertical relation of the birth rate to the death rate allows one to predict how the size of the population would change and thus, at what population levels one would find a stable population equilibrium. For instance, to the left of the right intersection point, birth rate is greater than death rate resulting in population growth and an associated shift toward the right of the graph. To the right of that point, death rate is greater than birth rate resulting in a decline of the population size and an associated shift to the left on the graph. There is a tendency for the population to oscillate about this intersection point which therefore represents a stable equilibrium. A similar analysis of the left intersection point reveals that the population size has a tendency to move away from the intersection which therefore represents an unstable equilibrium.

The decision to focus on these representations was made for several inter-related reasons. First, the representations are important to the field of ecology and were explicitly flagged as such during the lecture. Second, focusing on these representations allowed us to examine a step-by-step interpretation of a representation by the professor who was modelling for the class how to interpret a graphical representation that is often used in biology but which is uncommon in other fields. Third, it allowed us to study a ‘first

exposure' to graphical types which are uncommon in introductory biology courses in high school and university allowing us to gauge students appropriation and use of these tools for a given task.

Scientific Representation Practices and Reductionism in Ecology

At its foundation, ecology, as other natural sciences, is reductionist. Reductionism is an epistemological position to which the participants in the scientific enterprise become enculturated during introduction to the beliefs, practices, concerns, and resources of a discipline. In practice, scientists compose papers which are reductionist in appearance, but then synthesize these research papers in review articles to develop understandings of larger conceptual issues (Sinding 1996). Even then, their understanding of the larger issues (based on research projects) are contextualized by an understanding of how the smaller studies were conducted. Thus, although there are admittedly imperfections in the process of knowledge construction, the reductionism of individual studies is mediated (when seasoned scientists conceptualize large issues) by understanding the reductive process.

In lectures, students are often taught about the end results of scientific research; they hear about what Latour (1987) termed ready-made science and black-boxed science. Ready-made science is decontextualized and lacks any discussion of how it was created (thus the black box phenomenon). This puts students into the difficult situation where they have to re-construct understanding of the larger issues on their own. In lectures, students experience several aspects of reduction: complex situations reduced to two or three variables, clean graphs that lack the variation observable in real data, and decontextualized representations that lack reference to the work that brought them about. In the lectures we observed, the situations presented to students were also intended to present the biology context rather than the theoretical constructs by themselves. Many examples were tagged as "biologically realistic" such as the population graph (Figure 1b) that was "biologically realistic if. . . individuals have trouble finding mates at a very low density." Furthermore,

the instructor was explicit that he expected students to “be able to interpret shapes, plots like this in relation to the biology of the situation.”

This then raises the question central to this paper, are the “reductions” (i.e., in complexity, through data transformations, etc.) that are consistently used in lectures as organizational and framing devices hindrances to students appropriation of the more holistic interpretive understanding of scientists and the domain specific practices, concerns, and resources of ecology? To address this we discuss our findings from three perspectives:

- the portrayal of variable choice in lectures misrepresents their selection, development, and usage in ecology;
- the ambiguities in the empirical or theoretical origins of representations influence their interpretation; and
- the simplification of relationships between variables in lectures misrepresents their actual relationships.

Each of these lecture practices may contribute to the enculturation of future ecologists to a reductionist worldview.

Reduction of Complexity: Collapsing the World into a Few Variables

Factual presentations

In the ecology course, the variables represented in graphs were presented fact-like and decontextualized; there was little discussion about the nature of any variables and the purpose of their selection. Practicing field ecologists understand that their chosen variables represent but a few of many possible ones and incorporate this understanding into their interpretations and claims. To the students in the ecology course, however, this reductionism was invisible. For example, any decision to focus on two or three (or more) variables in a particular study is a decision to choose some variables as important and worthy of examination and to reject others as being unimportant for the particular

phenomenon being studied. In order for for students to appreciate the “reductionism” present in a scenario they would first have to know that there were other variables that were might have been important influences on the scenario and secondly have some understanding of the why some variables were selected and others rejected in constructing the study. In the resource lecture (Figure 1a), the array of examples might well lead students to understand that there was a considerable number of possible resources to look at, but no opportunity to try to understand why those specific variables were chosen for discussion over any other possible variables. The following excerpt from the lecture transcripts illustrates this argument as the lecturer provides a literal reading of the graphs depicting resource interaction:

Substitutable resources, they are substitutable, either can replace others, they may not be equally good. So if you're a lion or cheetah, or on a savanna—well if you need zebras or if you need gazelles they are both pretty much as good. Similar to each other as resources [you can] either live on, over a year, 30 gazelles or maybe 20 zebras. And another example of this is when you're on an airplane and flight attendants come down the aisles and say 'Chicken or fish, chicken or fish, chicken or fish.' Well they're substitutable in here, it may be better to say, 'They may not be equally bad.' This isocline [POINTS TO Figure 1a.1] shows substitutable resources. If you have a little bit of R2 and quite a bit of R1 [MARKS p5] the population will do about as well as if it has a little bit of R1 and quite a lot of R2 [MARKS p6]. So you can substitute one for the other. They may not be good but we can substitute.

This episode is typical for the way in which students were presented with examples of variables (i.e., types of resources) without any context of why these variables were chosen for study. In the lecture about resources students were presented with a large number of “examples” of the different outcomes from the interaction between two nutritional

resources. Yet, even in the talk of resources that preceded it there was little mention of the variety of resources necessary for organisms to survive. The various examples offered represent a bewildering range of categories, units of measure, and outcomes of effect (Table 1). Even with the range of resource types that were used as examples, there existed few opportunities for students to learn about the range of possible resources specific to an organism and therefore they had little context within which to place their understanding of the relationship between two resources when re-constructing the larger picture that constitutes understanding a “realistic” situation.

[INSERT TABLE 1 ABOUT HERE]

In this presentation of resource interaction, variables were presented as a matter of fact; there was little discussion about why two specific resources were chosen for study. Our interviews with scientists showed that they usually need such context to re-situate the results of any one comparison within a broader understanding of ecology and resource use (Roth & Bowen 1998). Choice of which resources would be used for study would be unlikely to occur for arbitrary reasons and yet the choice of specific variables for interaction studies is not a transparent process for newcomers to the discipline such as the students in the course. The lack of descriptive context is therefore particularly problematic for students in a class where students, for the first time, learned about resources and their interactions and, also for the first time, faced a two dimensional depiction of those interactions. Students are listening to the talk about ecology as newcomers, without the insight that field experience lends to the comments being made, listening to lecture talk that is structured as if old-timers were telling their autobiography.

Buying in

Any decision to focus on two or three (or more) variables in a particular study is a decision to choose some variables as important and worthy of examination and to reject others as being unimportant for the particular phenomenon being studied. For students to

appreciate that a scenario is “reductionist” they would have to know both which variables had been rejected that might be important influences on data interpretation and also why the studied variables were considered to be of importance relative to those which left unexamined. For example, the population graphs (Figure 1b) were presented as matters of fact rather than as a hypothetical model. The graphs re-present death and birth rates of a single population as a function of N (unspecified as population density or population size). Students were asked in a seminar problem to compare the relative influence of the two rates on population change. The question itself refers to the situation being biologically realistic if “individuals have trouble finding mates at very low densit[ies].” In this scenario there are therefore four separate variables considered to be relevant, whereas other possible variables are left undiscussed.

Our analyses of students’ discussions showed that they bought into the reductionist approach. For example, they spent considerable time and effort trying to place the population graph in a plausible ecological context with their other understandings; at the same time, their discussions suggested that they had insufficient experiential resources relative to ecology to aid their interpretations.³⁰ What warrants some reflection in considering the biological “reality” of the situation are the variables *not* discussed. For instance, the species of organism involved affects whether the animal can move or not and this ability to move affects the ability to both find mates and re-cluster into smaller geographic areas. This ability to move and re-cluster is an important aspect of whether the situation *is* biologically realistic or not. Yet, students did not have the interpretive resources to address any of these other variables. Furthermore, any attempt to bring in other variables

³⁰ A detailed analysis of students’ interpretive efforts relative to the population graphs was provided elsewhere (Roth & Bowen 1998).

was stopped by the teaching assistant who emphasized that they should only focus on the variables presented in the scenario.³¹

Student discussions did not make sense of the reduced model in the context of a broader picture of other related variables. Death rate was taken at face value as a clearly defined variable without discussion of the density-independent factors that can affect it—such as variations in predator populations, food resources, and other variables which themselves vary without correlating with population density. This is in contrast to some of the scientists' discussions in which the specifics of the determination of the variable "death rate" were considered to be important to the specifics of their interpretation of the graph. Students did consider the problem *ceteris paribus*, as one in which all other external factors remained constant and only changes in the target population are relevant. Complexities of variables, such as occur when the varied influences on death rate are considered, were reduced to being unitary in effect. We found, in subsequent focus-group interviews, that this difficulty with embedding the graphs' variables in the larger context of potential variables and influences seemed to considerably hamper students' developing a plausible interpretation of the graph.

Constructing variables through embodied work

The choice of variables in scientific work is not self evident but driven by considerable number of local and global factors (Knorr-Cetina 1981). Newcomers to scientific practice face a discontinuity going from the factual and simple world of lectures to a world full of complexities. The following field note reveals the lived work (Bowen's) of selecting appropriate variables. This episode illustrates how the choice of variables to study is

³¹ Similar comments ("focus just on the information given") were provided by scientists to grade 8 students in a study on representation practices (Roth 1996). Such comments appear to be typical though implicit for individuals who have been enculturated into reductionist worldview when they attempt to enculturate newcomers into the same worldview.

embedded in past research findings and other mediating factors representing aspects of the concerns and standard practices of ecologists.

In the earlier stages of the design of my research project there was some discussion about which two contaminants should be tested. The behavioral work took a considerable amount of time which meant that only one comparison could be done. Because of the amount of literature on heavy metal pollution and their prevalence as anthropogenic environmental pollutants it was decided to focus on heavy metals. . . . I ultimately chose copper and zinc as the test metals because they came from a similar chemical category and for this initial foray into looking at the effects of mixtures on behavior it was decided that examining two common pollutants of somewhat similar chemical effect made the most sense.

Here, the choice of variables is not arbitrary, but rather is a function of the research context and the contingencies of the situation. The amount of time an experiment would take, existing literature, and “what makes sense” were crucial to the selection of the variables rather than some criterion of truth. Despite the considerable considerations that goes into the choice of variables in a scientific investigation, the ecology course provided the undergraduate students with few opportunities to engage in such considerations themselves or even to realize that others had engaged in those “considerations” in producing the facts they were learning.

Theoretical Models and Real Data

A second major hindrance to understanding graphs and their worldly referents lies in the indistinction between graphs which depict mathematical models and graphs that are best-fit curves to data collected in the field.³² Because lectures—in the same way as

³² We described elsewhere the difficulties even graduates of science programs (B.Sc. and M.Sc. degrees) had to determine whether there is a relationship between two variables when the data did not fall on a clean line (Roth, McGinn, & Bowen, 1998).

textbooks (Roth, Bowen, & McGinn in press)—do not distinguish models and real data, students develop a reductionist view of the world and believe that real data should follow exact mathematical laws (Roth 1996; Roth, McGinn, & Bowen, 1998). That is, students adopt the isomorphism in Wilson's couplet {world $\longleftrightarrow$ mathematical structure} as fundamentally given.

In lectures there was little mention, apart from a few passing comments, that models being used were drawn from a combination of data and a theoretical perspective. Competing theoretical perspectives can often mean that different models with different implications can be drawn from the same data. Without experience with how models are constructed students are not likely able to reflect on the theoretical perspectives which drive the model and its interpretation. Models are abstractions drawn from many cases but the process of this derivation of the model and foundation of particular theoretical constructions remained hidden from students. The result of this 'hiddenness' was apparent in student conversations about the graphs in which they discussed the relationship between variables in terms which indicated that they were unaware of the complex relationships and transformations inherent in developing models. Thus, because they did not understand the derivation of models, students were further developing a reductionist view through reverting to discussions of non-complex relations between variables (as critiqued above).³³

The "cleaning" of data inherent in graphs is the reduction of data scatter. This reduction of scatter is a feature of reductionism in science resulting in generalized models. The 'realism' experienced by a biologist looking at such model representations lie not in the representation itself, but in the interpretive resources brought to them drawn from their own work constructing such models. Our data shows that practicing ecologists recognize models for what they are based on the clear *lack* of data scatter. The graphs which we have

³³ Even if models are understood, one can argue that they reinforce the concept that nature is, at its basis, mathematical which reinforces a reductionist/mechanistic worldview.

discussed which were presented to students (both the isocline and population graphs; Figure 1) are theoretical models of relationships and lacked the “messiness” of representations of real data, but were not recognized by the students as being models. However, to biologists this lack of scatter quickly leads them to the assumption that the representation was a generalized or theoretical model. When these same graphs were presented to a field biologist he quickly concluded he was dealing with theoretical or generalized models and framed his discussion of them based on this. Among the first comments each one of the practicing field ecologists made were those related to the idealistic nature of both graphs and their uselessness to practical work.

The second-year students did not make such a distinction and their subsequent interpretations were not framed as if these were theoretical models. Models are a specific form of data transformation which are often quite complex in their derivation and students have few interpretive resources upon which to draw to make the distinction between models and ‘real’ data. Our interviews with scientists indicate they often contextualize their interpretations of graphical models by moving back and forth between their knowledge of real populations and their understanding(s) of related theory.

In the lectures the instructor continuously integrated resources (i.e., personal experience), units of measure, and possible effects of resources as he described resources and isoclines to the class. Yet his students did not have the interpretive resources nor did they make the linguistic distinctions necessary to shift between considerations of data and considerations of models. In their seminar discussions of representations of models, part of the reason students experienced breakdown in their interpretations was because of difficulty they experienced in making these linguistic distinctions between models and measured data. From their discussions it was clear that this difficulty in making such distinctions complicated their efforts at arriving at canonical interpretations. Additionally, not distinguishing graphs representing models from those representing data means that students

had to accept such truth-claims as “fact,” ignoring the interpretive stance adopted in developing that claim.

A theoretical ecologist commented on the population graph calling into question the purported relationship between birth and death rates on population growth:

There are a lot of people that don't believe there is any evidence for this kind of effect. . . . A lot of people challenge it as being unsubstantiated empirically.

There's no evidence for it at all.

However, he also discussed its use as “scaffolding around which to hang my thinking about population ecology” and in particular discussed it in relation to other variables such as competition for resources with other species that would have an effect on its interpretation. To this ecologist, and others that were interviewed, the scenario presented in the question *could* be discussed in isolation of other variables but *only* made sense in consideration of other variables not included in the graphical inscription. Although he suggested that the variable choice was perhaps not substantiated empirically, the theoretical ecologist still said that he used just such graphs as “thinking” tools and that he was aware of other variables that were not used in the derivation of the model.

From Data to Clean Graphs

Our ethnographic work in a field camp of working ecologists shows that the construction of graphical representations is a protracted process including several steps: Scientists make decisions about the nature and location of the world's joints that are suitable for investigation (identification and selection of variables); they choose instruments that inscribe nature on paper; and they use mathematical and statistical tools for domesticating raw data and turn them into clean graphs. Reduction of complex situations to those variables that are both distinguishable and measurable is a characteristic of reductionism. When one has participated in such ‘cleaning’ one takes that into consideration when interpreting the final representation. However, this is less likely to

occur when one has not engaged in the ‘cleaning’ oneself. In this section, we provide a phenomenological analysis of learning to do the work of cleaning data.

As part of his masters degree, the lead author conducted a study of the effect of two metals on fish behavior. In the process, he learned to first construct “clean” isographs from his data set (of the type shown in Figure 1a) followed by his first interpretation of them. In this learning process, he personally experienced the tension between what he had come to accept as truth, clean graphs that showed nature as it really is, and the messy and scattered nature of data ecologists normally collect during laboratory and field work. If the struggles of a graduate student are held against the unproblematic presentation of the clean figures during the ecology lessons, one is led to conclude that lectures mislead students into understanding nature as a series of unproblematic, “clean” relationships between variables. Science-in-the-making deals with data that seldom shows the clean patterns and trends of graphs in textbooks (and lectures):

I first played at great length with the graphing program using my original data set. First using measured levels of the metals (which were wildly scattered), then using the expected levels, back to measured, back to expected, the hope of using new measured values, and settling on using the expected values. Yet, despite all of the “playing” with what levels of metals to use (measured or theoretical) the use of my raw data for the response resulted in a completely un-interpretable surface projection. Even with all of the “playing” to get a surface (which was subsequently represented in contour 2-dimensional fashion) I was completely dissatisfied with the results. The resultant isoboles were all over the place—not at all like the “clean” ones I had seen—and essentially indecipherable from the perspective of determining which of the three conditions were in effect. I did this “playing” for quite a while, trying different contour intervals, data transformations, etc. Nothing looked useable so I resorted to the canonical approach of constructing a data table based on the

mathematical model I'd developed from the data. . . . And this generated a smooth 3-dimensional graph and 2-dimensional isocline representation which was therefore more interpretable.

This episode shows a struggle, a reflexive to-and-froing movement between the data, the model, and the graphing program in attempting to generate an isograph that resembled the one found in the reference he was using. It was only after considerable effort attempting to graph his raw data set that graphing a surface-based on the mathematical model of his data which resulted in an isograph that resembled published ones—became a plausible option. This “model” isograph was one which he could interpret according to canonical rules and led him to realize that what had been graphed in his reference was a model based on the data, and not the data itself. An understanding of this developed not from reading articles but from an enactment of graph-related practices which therefore were part of embodied knowledge.

Despite the construction process, Bowen's initial interpretations of isoclines were based not on understanding how the juxtaposition of lines on the graph were related to the interactions between the metals but rather were drawn from his understanding of the mathematical formulae derived in his analysis. As long as his own isoclines and mathematical models resembled those which he had been using as an interpretive reference he could interpret them. The interpretive difficulty arose when there was deviation from these “norms” of interaction portrayed in his reference.³⁴

When I initially thought about ‘additivity’ versus the other types of relationships between copper and zinc (being synergy and antagonism) I thought of it from the perspective of the mathematical formulae used to describe the relationship and realized that “additivity” meant that there were no significant interactions between

³⁴ The example isographs used as an interpretive resource closely resembled those illustrated in Figure 1a. His initial interpretations of those graphs were not unlike those interpretations made by the students in the ecology class when asked to discuss one of their exam answers after it was returned.

the copper and zinc or that there were no higher order terms in the model. The reason I had to resort to isoclines to “figure out” how to interpret the relationships because my model had a higher order term in it and I was uncertain how to interpret the interactions from solely a mathematical perspective. . . . However, when I finally generated clean isoclines they still did not look like those in the book. Whereas the reference book showed consistent patterns, my isobole had on one side straight lines, which then changed to curving lines. I struggled for a long time with how to interpret this.

As presented in lecture (and their textbook) students developed an understanding of interactions between resources which placed the possible outcomes in discrete categories: resources are only one type, additive, complementary, antagonistic, or essential. However, mathematical models (on which the isoclines are based) with higher order terms and small “constant” terms may show one of these types of interaction at low levels of resources and a different type of interaction at higher concentrations. This was the situation the lead author faced in his own training, and one that he suggested took considerable time to resolve because his expectation was that the interactions would fall into discrete categories such as those presented in to the ecology students (Figure 1a).

The presentation of isocline graphs in the lecture (and in the textbook) which compare the effects of pairs of resources does not discuss more complex relationships. Yet, there are good biochemical and geochemical reasons that they exist. How does this then affect the students enculturation into the practices of science and their expectations of relationships between variables? Wrestling with his data set, the lead author initially had considerable difficulty interpreting the isograph. In part, the difficulties arose from his attempts to use the “clean” framework in his academic references as referent. An acceptable interpretation of the isograph was reached, over a long period of time, as he learned to appreciate the complexity of interactions:

In my initial attempt to interpret the isobole diagram I was quite confused because the figure I had finally generated looked like none of the example isographs in the book. Which was it: Additive? Synergistic? Antagonistic? I was initially quite uncertain about the interpretation of the graph. From the algebraic formula I knew that there was additivity of lower order terms, but also that there was a higher order term as well. It was only after starting to play around with a printout (instead of trying to interpret the representation on the computer screen) that I covered part of the graph with my hand and realized that if I covered the left half it looked less-than-additive and if I covered the right half it looked additive. Even that puzzled me a little, until I played with a calculator and thought about the effect of “squaring” on really low numbers. Then, and only then, did I realize that at very low concentrations the higher order term in the mathematical model had little effect. This finally resulted in my understanding (and accepting), from both my data/formula of the surface and the representation, that both additivity and less-than-additivity were occurring.

These autobiographical notes document that interpretation of graphs is a reflexive process of moving back and forth between theory (the “clean” isoclines he was using as a reference) and data. An understanding of isoclines, their interpretation, and, most importantly, the ecological significance of what they were portraying developed as a result of these reflexive moves. Opportunities to work with the data, such as illustrated in the field notes, were not available to the ecology course students. Rather, students’ interpretive processes of the population change graph (Figure 1b) showed similar struggles without the opportunity to arrive at a closure such as that provided by a completed M.Sc. thesis.

This description of the process of generating an isograph in a toxicology study reveals the difficulties involved in generating the ‘clean’ isoclines presented to students in the ecology lectures. The interpretation of isoclines is not as straightforward as presented in

both the lectures and the textbook, yet that is not something that the students would understand about either the interpretive process itself or about the possible interactions between resources. This is because in the presentation of the isographs in lecture, four possible interaction relationships were given (three of which are depicted in Figure 1a) and were portrayed as being unique and, most importantly, discrete from each other. Despite the obvious degree of work involved in the generation of an interpretable surface, students had few opportunities to engage in similar processes, consider why such studies would ultimately be done, or construct such a representation on the basis of realistic data sets. Thus, despite the lecturers' assertion that the examples he used were biologically realistic, there were no opportunities for the student newcomers to ascertain, through their own lived experience, the degree to which the graphs could be termed realistic.

An excerpt from an interview with one of the ecology students leads further to the conclusion that the presentation of simplistic relationships in graphs may lead students to develop generalizations that are unintended. We had asked the student if the interaction between complimentary resources (Figure 1a) had to necessarily be a one to one correspondence with one resource having to equally replace another to have the same effect. He replied:

I think we were led to believe it was a one to one [correspondence] because it was a straight line there [Pointing at graph depicting substitutability; Figure 1a.1]. And it was forty-five degrees, if you just glanced at it it looked like a 45 degree [angle] so I assumed it was one to one from the diagrams as well. That one [resource] perfectly substituted for the other. When they said that they basically led me to believe it was the same amount as well. Same amount of one perfectly substituted for the same amount of the other.

Simplifying the complexities of biology for the purposes of instruction (such as was done with the graphs in Figure 1), where scales and units are both removed and complex

relationships are transformed into straightforward ones, easily leads even the best students to a reductionist view of ecology and to an enculturation into a typically modernistic, simplistic interpretation and understanding of ecological issues. Such simplification, the reduction of examples, numbers, or units occurs not only in lectures such as we illustrated here, but also in textbooks. Students are not aided in their understanding of the complexities of interactions by either the text or graphical inscriptions found in textbooks since the decontextualized fashion in which they are presented makes them difficult to read and interpret (Roth, Bowen, and McGinn in press). This emphasizes the importance of engaging students not only in the practice of science but also in the writings of science itself as found in the writings *of* science, in journals for instance, as opposed to writings *about* science, such as found in textbooks and magazines.

Discussion

Scientific reduction can take many forms, of which one important one is how the variables to be studied are chosen. Any given phenomenon can be parsed in an infinite number of ways resulting in an infinite number of possible 'variables' to be examined. When scientists reduce the identified variables to a manageable number for experimental or modelling purposes, they can either "cluster" variables into like categories from which exemplars are chosen for study or identify variables of interest and eliminate from consideration factors which are external to those variables.³⁵ The selection of variables, and the reconstruction of holistic understandings from them, is driven by domain-specific concerns. Apart from the domain specific concerns of ecology, some even argue that ecology is somewhat different from other "hard" sciences when it comes to the choice of variables to study and how those are then interpreted. In commenting on ecology as a predictive science, one professor of environmental science argues that he

³⁵ Of course, in any experiment, these approaches are concurrent to varying degrees, but for rhetorical purposes in comparison with the lecture/seminar topics they will be treated separately.

can think of no ‘hard’ science as helplessly adrift on an endless sea of variables, their process relationships so complex that no individual mind can either encompass them nor corral them for computer counting. Ecology does not know what its variables *are*, much less how to project them. When you remember that ecology is site- and situation-specific, forecasting . . . is no more than a nonsensical contradiction in terms. Ecology cannot predict in the scientific sense, it can merely describe. (Livingston 1981, p. 66, original emphasis)

Understanding the compromises made in choosing variables and the field-mediated and theory-related concerns which guide those choices is an important aspect of interpreting data. The influence of context on variable selection and interpretation was evident from other scientist participants in our studies. For example, in an interview a field biologist working in fish population management suggested that some of the variables he used to derive allowable catch recommendations were partly based on the foundation that they seemed to “work,” in that the fish population was maintaining its size, rather than for any grand theoretical reason. More importantly, understanding how those variables were chosen and the data collected is important in judging the credibility of particular data sets. Our ethnographic field observations with ecologists studying reptiles revealed that variables were chosen because of their “availability” based on time, personnel, and equipment restraints. However, they also realized that some of the data was likely to be unhelpful, but collected it “because they could” and because meaning might arise for it later. They gauged the quality of the data (and the inscriptions which recorded it) based on their understanding of the variables being studied relative to those which could be but were not for various time, equipment, or other logistical reasons.

Scientists, in the same way as the graduate students we observed, talked about picking variables they think are particularly significant, deciding how to operationalize them, designing studies, collecting the data, and then using their knowledge of that whole process

to interpret the data and decide on its significance. To the students in their second-year course, scientific claims and their significance were not embedded in an appreciation of any of the contextualization that occurs in the process of deriving the claims. Thus, students had little choice but accept lecture talk as truth. In this case, from this segment of the lecture they take the claim that resources exist, that relationships between them are clearly categorizable and can be labeled, and that this does have a biological effect.

Field data is “messy” relative to the final “clean” representations which appear in published papers. The data sets often go through iterative mathematical transformations making the resultant representations appear “clean” compared to how they would appear if the original data set were graphed. Interpreting the final “clean” representation canonically requires knowledge of and experience using the types of transformations to which data is subjected to generate the “clean” representation (Roth and Bowen 1998). The resource and population growth scenarios presented in lecture and seminar were both portrayed as being ‘biologically realistic’ yet the graphical representations of them bear little resemblance to the ‘messiness’ of data collected in experiments.

Lecturing students about these types of interactions does little to help them understand the relationships between the graphical presentation and the mathematical models from which they’re derived. As a result, students did not draw on the same interpretive resources as researchers or lecturers. Our research with graphical interpretations done by pre-service teachers, many of whom had taken this ecology course in a previous year, suggests that not understanding underlying mechanisms and the complexity of the relationships between variables led them to conclude that unclear relationships, such as often exist in raw data, are non-relationships (Roth, McGinn, and Bowen, 1998). We contrasted these interpretations with those of grade 8 students who had participated in open-inquiry “authentic” science classes in which they constructed graphs to draw conclusions from their own data (Roth 1996). In contrast to the teachers, the grade 8 students addressing the same written problem

often argued for their being a relationship between the variables. This highlights the importance of engaging students in the development of such graphs so that the possibility of complex relationships is encountered and explained in ones own work.

Scientific reductionism often masks the complexity of the interactions which occur in nature. Our understanding of nature is partly affected by this through our tendency, when teaching 'science,' to separate it into various subjects. However, even within a particular subject or course further segmentation of topics and subtopics occurs which leads to a fragmented understanding of the subjects. Ecology could be taught more effectively if lectures made explicit that practical problems are more and more solved at the interface between several disciplines (Barrett, Peles, and Odum 1997). This also holds for the interfaces between topics within a discipline, but to be able to recognize these "interfaces" there has to be an attempt to enjoin the different areas. Barret et al's review of the literature further revealed that students are typically taught to consider only a limited range of organizational levels to address a particular process or mechanism. Such a conclusion could also be drawn from transcripts of the lectures in this specific ecology course. The reductionist presentation of topics leads to a view of problems being solved according to the interpretive framework of a single topic area. Thus, students' interpretations of isographs did not draw on any other topic from that course as a possible resource for dealing with the experienced interpretive problems.

Various aspects of the lectures, especially the connections between topics, stood in contrast to our understanding of the concerns and practices of working scientists. Lectures often make few attempts at linking topics, even isolating them in separate sections of the course, and often do not discuss underlying mechanisms which influence those topics. Students in ecology are often presented with scenarios that exist in conceptual isolation from others to which they are related. In lectures students are faced with ontological jumps as lecturers move from one domain to a related one. Students are expected to follow these

jumps. This may represent how old-timers move around the conceptual terrain because of their familiarity with it, but to newcomers the conceptual terrain is not so easy to navigate. To the lecturer, movement between different conceptual areas is perfunctory because they understand the underlying mechanisms, however to the students such movement is problematic because they are unaware of the underlying mechanism so to them there is no logical connection between the areas. In the lecture about resources the lecturer moves from talking about resources to talking about interactions between resources. Such a move is transparent if one has some understanding of the biochemical principles underlying the concept of “resource,” but becomes opaque if such underlying mechanisms are unknown, such as they often are by students (such as those in this class) who have not yet taken biochemistry courses. This opacity lends itself to developing a reductionist view as one accepts the end-point “facts” as representing science instead of considering the data collection an interpretive process as part of those facts.

The centrality of graphing to the practice of science is an important mediator of this reductionism because of the physical limitations of graphing relationships between variables on paper. In other words, one of the key factors in the reductionist tendencies of most science is the limitation to visually represent more complex relationships in two-dimensions. Thus, whereas there accrues an enormous benefit from the two dimensions of inscriptional media (Latour 1987), this form of the medium enforces a particular approach and epistemology on the part of those using it. The medium if not the message—as Marshall McLuhan would hold—communicates, and thereby encourages the development of, epistemological frames (Brown and Duguid 1996). For working scientists to overcome the reduction of complex ideas to a few variables, they need to be able to reconstruct their understanding of the “larger picture” based on their experiences in having reduced complex situations to a few measurable interactions in the first place. What our analysis therefore calls into question is the propensity to “lecture” about complex biological issues without

giving students the opportunity to develop their discursive and material resources as they appropriate the standardized practices of the discipline. Students have at best opportunities for learning only about the factual claims of science but little about the practices or associated resources themselves.

The repeated moves by scientists when solving problems between the “data” and the representation reaffirm the isomorphism {Fundamental Structure <--> Mathematical Form} which is taken as fact in the natural sciences (Lynch 1991). The understanding of issues by scientists has been shown to develop through such iterations and it is notable that such iterations did not occur within the lectures where the interpretations of the isoclines was essentially presented as unproblematic and unidirectional to the students. Students experienced neither the practices that give rise to the couplet nor the interaction between the two features of the couplet which allow scientists to build and increase complexity of their understandings of issues.

The processes of interpretation of graphical representations is by no means straightforward (e.g., Bowen and Roth 1997; Roth and Bowen 1998; Roth, Bowen, and McGinn, in press). Suggesting otherwise does little to aid students’ understanding of either the complexities of a given situation or of science itself. As a consequence of having fewer fieldwork experiences, students bring fewer resources to the interpretation of graphs than do scientists themselves. This makes lecturing a particularly problematic type of instruction because if sufficient context is not developed in lecture, students themselves have few resources to bring to the task of interpretation. Even students who spend time discussing the interpretation of complex representations have difficulty in developing a canonical understanding if sufficient context is not provided (Bowen and Roth 1997). It is unclear how one could structure a lecture so that practices learned in class could be transferred to the field and vice versa. Grade 8 students presented with a word problem representing field research experiences with which they had spent considerable time did not simply transfer

their mathematical practices from the field to word problem situations (Roth 1996) and the related stories of the biologist using isographs to address the issues of interactions between metals suggest that the reverse does not easily occur either. This then raises the question, is there such a thing as a biologically realistic scenario from the perspective of lecture instruction?

There is little evidence that students learn to use graphs from being presented generalized graphical representations. On the other hand, there is evidence that experienced ecologists engage in interpretations which draw on a dialectic of personal experiences and concrete representations of particulars (Bowen, Roth, and McGinn 1997; Roth and Bowen 1998). In this light, it would seem that the use of graphs in lectures is counter-productive: students are not learning graphing practices as they are practiced by scientists and they are further enculturated into a reductionist world view that is in opposition to currently promulgated popular “ecological” perspectives. This suggests that we need to further examine the structure of our science classrooms to better understand the implicit messages about science we are communicating through how we structure the lessons.

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Table 1: Discourse elements for talking about variable interaction and isographs

Resource Type	Resource Units	Effects of Resources
potassium	"units"	none
calcium	pounds	growth
magnesium	kilograms	growth rate
nitrogen	milligrams	"live on"
molybdenum		maintenance of health
gazelles		maintenance of population
zebras		
chicken		
fish		
amino acids		
lyzene		
fertilizer		

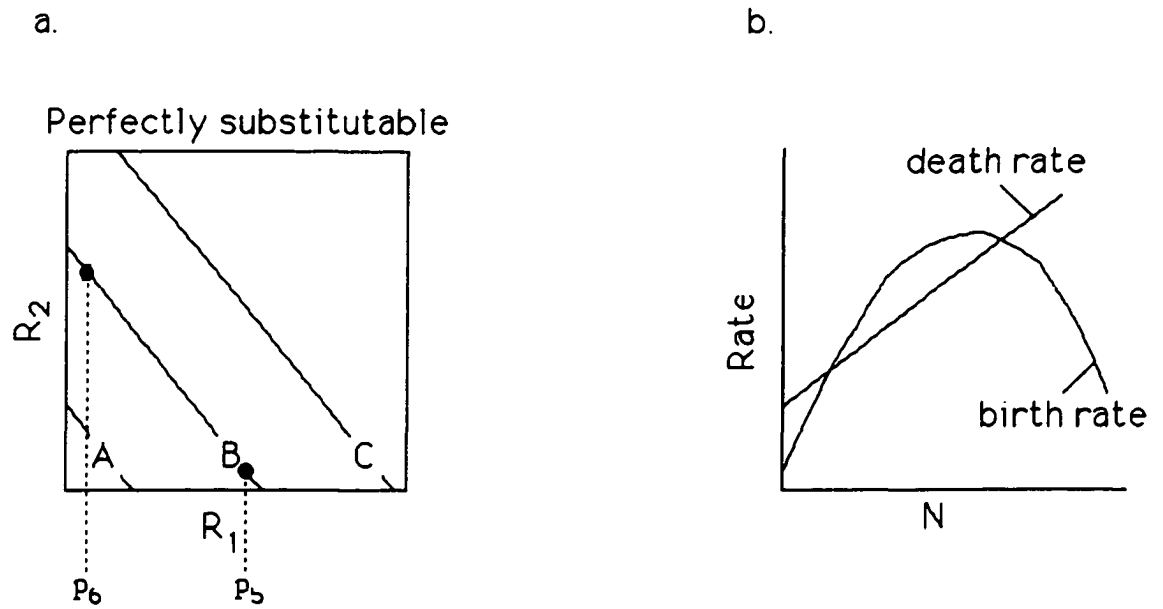


Figure 1: Two graphical representations used as part of a second-year university ecology course. a. Isograph show the interactions between two independent variables on a dependent variable whose variation has to be read by contrasting lines. b. The effects of birth rate and death rate which are functions of population size N on this same population size.

Chapter 8:

Of lizards, outdoors and indoors:
Translating worlds in ecological fieldwork

**Of lizards, outdoors and indoors:
Translating worlds in ecological fieldwork**

Abstract

The noted theoretical biologist Jakob von Uexküll noted in the beginning of the century that to understand the evolution of an organism biologists needed to understand the lifeworld (Umwelt) of the organism they studied for organisms react and adapt to their lifeworlds rather than decontextualized, transcendental worlds. In this paper, we show that in contrast to von Uexküll's precepts, the ecologists in our 2 year ethnography continuously attempted to construct a transcendental world which had decidedly human (and most often rather mundane) categories/dimensions. Based on our ethnography among ecologists, we show that their research practices ran counter to an understanding of their organisms' lifeworld, and therefore counter to a better understanding of the dynamics of the natural history of the organism and the environment within which it lives.

The research world of physical scientists starts as they walk through a door and into a special building which contains their laboratories—in which they conduct most of their research. For ecologists however, their research world starts when they walk out through the door of that special building which houses their laboratories and into the rest of the world. This is relevant to the development of (research) attitudes towards nature because ecologists learn about the research practices of their discipline in settings (in large groups in university lectures or laboratories) and with organisms (often dead³⁶ or preserved) quite different from the actual settings of the disciplines research. This has important consequences for how field biologists learn to frame their understandings of the organisms they study, particularly when they conduct research on organisms which they themselves interact with and have an embodied understanding of the world.³⁷

Living organisms react to the world in a way that is meaningful in terms of their own needs; they process information in accordance with their receptors, nervous systems, effectors, and in terms of their own codes. Biology can therefore utilize causal and mechanical explanations only to a limited degree. The task of ecologists should be to reconstruct the meaning of an animals behavior, which implies finding out which sign processes underlie this behavior,³⁸ because there is a structural correspondence/coupling between each living being and its Umwelt, that is, the world as subjectively experienced by the organism.³⁹ The relevant processes for an organism's actions/reactions are the sign

³⁶ The dissection of dead animals results in animals being regarded as "mere specimens" and develops/reinforces a cultural understanding of science and its beliefs about the use of and power over animals. Solot, D. & Arluke, A. (1997) Learning the scientist's role: Animal dissection in middle school. *Journal of Contemporary Ethnography*, 26(1), 28-54.

³⁷ In the case of Pasteur, Latour (1988) showed that there was actually a double movement which took the scientists first into the field, then into the lab, only to end up in the field again where the lab situation was recreated to allow a generalization of lab results to field settings. Latour, B. (1988). *The pasteurization of France*. Cambridge: Harvard University Press.

³⁸ Krampen, M. (1986). Phytosemiotics. In J. Deely, B. Williams, & F. E. Kruse (Eds.), *Frontiers in semiotics* (pp. 83-95). Bloomington: Indiana University Press.

³⁹ Varela, F. J., Thompson, E., & Rosch, E. (1993). *The embodied mind: Cognitive science and human experience*. Cambridge, MA: MIT.

processes in which this organism is involved. So, if researchers want to understand why lizards are behaving the way they do in their environments, they need to see the environment in the way lizards do, rather than in the way we humans do. Lizards behave and evolve because of their interaction with their perceived environments rather than engaging in those behaviors in a transcendent world.

The construction of knowledge in field ecology often begins with fieldwork and then moves into the field laboratory.⁴⁰ When ecologists study the natural history of an animal they make selections—factors to be examined in the field, factors to be moved into the laboratory, and procedures to determine how that move into the laboratory occurs and is enacted within the laboratory—but subsequently claim (implicitly in their writing) that the world reported is the world as experienced by the animals. Ecologists act as if there is a transcendental world that they can reconstruct by collecting, purifying and transforming data. The outcome of this is that claims of the “natural history” of the organism are made which are identical to the worldview of the organism, or in Uexküll’s terms, the organism’s “Umwelt.”⁴¹

Elsewhere, we have argued that reductionist worldview of ecology is developed in undergraduate students through not just the content of their ecology course but through the epistemological underpinnings of how the course itself was taught⁴². Further, mathematical practices developed (as part of their research) to be locally adequate and defensible leads

⁴⁰ In this paper the term “field laboratory” will be used to refer to the building site at the field research site. This field laboratory is often much less of the specialized setting within which chemists and physicists and geneticists are found, but is typified by collections of data records into which the measures from the field are added, the presence of the lizards themselves, and some specialized equipment used in laboratory activities with the lizards. At the conclusion of the field season collected data, samples, and some lizards are physically transported and relocated to the laboratory found at the university.

⁴¹ von Uexküll, J. (1973). *Theoretische biologie* [Theoretical biology]. Frankfurt: Suhrkamp. (First published in 1928).

⁴² Bowen, G.M., & Roth, W.-M. (1998, April). Isolation of variables and enculturation to a reductionist epistemology during ecology lectures. Paper presented at the annual conference of the American Educational Research Association, San Diego, CA.

field researchers to make claims about what preferences or behaviours “all animals” demonstrate⁴³. Thus, broad informal assumptions or interpretations about the lizards’ world, mediated by available tools and a reductionist worldview within the community of research practice, occur at several critical junctures and determine how a transcendental world and the worldview of the animal emerges from ecologists’ activities. Drawing on ethnographic and autobiographical field notes, this paper examines how the animals’ worldview is initially framed by the researcher at these junctures—before the construction of tables and graphs to represent patterns—and what factors determine how this transcendental world within which the lizard lives, and then the anthropomorphic worldview of the lizards’ world, develops.

Research Context

As part of a study attempting to understand how ecologists are enculturated into their domain and how they learn to make sense of their world, GMB participated as a field assistant during five weeks of a field season in which one ecologist in her third year of doctoral studies (plus two years of field work for her M.Sc. work), Sam, collected field data on a lizard subspecies. In the course of this work, GMB participated⁴⁴ in the data collection in both the field and the field laboratory during which extensive notes and hundreds of annotated digital photographs were recorded, formal and/or informal interviews were conducted with the various participants involved in studies in the area⁴⁵, and photocopies of paper artifacts, including data records, were accumulated. Videotape records of pivotal events in the field and field laboratory were also made. This work was

⁴³ Roth, W.-M., & Bowen, G. M. (in press). Digitising Lizards or the Topology of “Vision” in Ecological Fieldwork. *Social Studies of Science*.

⁴⁴ We used apprenticeship as ethnographic method. See, Coy, M. (1989). Being what we pretend to be: The usefulness of apprenticeship as a field method. In M.W. Coy (Ed.), *Apprenticeship: From theory to method and back again* (pp. 115-135). Albany, NY: State University of New York Press.

⁴⁵ Other field biologists were also conducting research projects on snakes, frogs, and birds in the area and the lizard project itself had various assistants over the duration of the summer.

contextualized in our analysis by records made as GMB attended symposia/conferences with the graduate students engaged in this field research, socially interacted with informants⁴⁶ at least once a week in informal settings, visited various members of the community in their laboratory settings at the universities, and observed and had discussions with members who were working as teaching assistants for various biology courses at their home universities.

During the study, active analysis of the field data was conducted by members of the research group—in part to help establish the “credibility” desired in ethnographic research⁴⁷. While conducting the field study, to counterbalance any assumptions and presuppositions about field research⁴⁸, GMB emailed his field notes and annotated digital photographs to a non-ecologist research colleague (WMR⁴⁹). This allowed GMB to receive feedback on the focus he was taking in the field thereby providing direction for re-examining some issues in greater detail while in the field and also further examine features of the fieldwork unelaborated in his initial field notes.

Participants in the field research were: Sam the lead ecologist and doctoral student in her third year of studies who described her interests variously as investigating the ecology, the behavioural biology, and the evolutionary biology of her lizard species⁵⁰; Stephanie, her

⁴⁶ The “them” in this context represents the revolving membership in the community, not a “set” body of individual members.

⁴⁷ One method of establishing credibility is by “peer debriefing” (Lincoln, Y.S., & Guba, E.G. (1985). *Naturalistic inquiry*. Newbury Park, CA: Sage), such as the communication of field observations and tentative analyses which occurred during the conduct of this ethnographic work.

⁴⁸ GMB worked for several years as a field biologist and has a BSc and a MSc, the former in marine/aquatic biology and the latter in aquatic toxicology.

⁴⁹ WMR was “non-native” in two senses. His academic background was initially in physics research and he was removed from the research field and was only experiencing it through the notes and photographs.

⁵⁰ These are not contradictory as the fields conceptually overlap and in essence constitute different lenses through which the same data may be observed and collected. However since the “ecology” aspect is experience-near to the field work GMB conducted and the “evolutionary biology” aspect is experience-distant (essentially being developed in the interpretive stage back at the university lab) she will be referred to in this paper as an ecologist.

field assistant who had completed a BSc and had worked as a field assistant on other projects; Jobe, a post-doctoral fellow conducting another project in the area who Sam used as a sounding board for her research design and interpretation; various other graduate students and non-biologist volunteers, and; her supervisor and several other graduate biologists who provided support or advice by phone or e-mail.

Into the “Outside”

Engaging in ethnographic research with our ecologists took us into three significant places: the university laboratory, the field laboratory (about one day’s drive from the university), and different field sites scattered in the vicinity of the field laboratory. Each spring and summer (April - September), the activities moved from the university to the field laboratory and sites. Open-air studies were conducted on most days of the week, but whether they were conducted on any specific day depended on a large number of mitigating factors warranting consideration. The other secondary considerations (e.g., follow up work in the field laboratory not yet completed) aside, the primary components of fieldwork could not proceed unless both the weather and the lizards themselves cooperated. The following narrative lays the terrain for the conduct of the field research and factors that shape the anthropological construction of the lizards’ world.

Looking out the early morning window, Sam took a view of the sky.

Having caught up on the other lab work that needed doing, it was now possible to proceed with site work—she was prepared to start working a new field site. Listening to a weather forecast coming from a radio station two mountain ridges away, she made a judgement based on her view out the window and the comments of the radio announcer on whether today would “be a good day” to go into the field.

In the sense that Sam intends “good day”, she means, ‘Will the lizards be out?’ ‘Will it be a good day to catch lizards?’ and ‘Is it worth hiking in to the rock strewn, flower and weed covered hillside to where her study site is or will today be a day when it is unlikely that the lizards will be catchable?’ The decision she makes is based on her sense of whether it is a good day to catch lizards which is based on considering if the lizards will be out-in-the-open in the field areas (as opposed to being in the brush or rockpiles) where they are caught “under” rocks. She is assessing whether the hike into the new area will be fruitless—there is little sense in spending the day going into the field if the chances of catching lizards are slim, for there are other issues that do need attention. Her decision is not based on whether it would be a good day for the lizards themselves, for arguably being caught by an ecologist even with good intentions is not in an individual lizards’ best interests. However, the assumption could be/is made that since they are to be found at this location and not some other, that this is an example of a “good ” place to spend time, or at least the lesser of “bad” places. Thus, being situated in this locale is in the lizards’ “best interest” by virtue of it being found there in the first place. So run the tautological explanations of field observations of animals found in ecology.

It is at this point in the early morning light that the first abstractions and assumptions about the lizards’ world, their individual umwelt, occurs, for it is here that the assessment is made by a human about conditions which will influence lizards presence in the open, slightly rocky areas where they can best be caught. There, in the right weather conditions at the right time of year, the “best interests” of lizards and scientists overlap, because it is in this location that one can find the other. In the other lizard “worlds,” such as in rock piles, the interaction between lizard and environment is such that the humans world essentially does not overlap that of the lizard—in other words, the lizards are uncatchable in those settings, as well as in the forest. Lizards also live in those worlds, or at least our ecologists

speculate they do, but those worlds are constructed in such a way that the scientists have little expectation of being able to find them there.

In this, the lizards' perceptual apparatus (both physically and as guided by lived experience) is so different from those of the human ecologists that their respective worlds do not overlap—their reactions and experiences within the environs of rock pile and forest are so different that they are uncatchable. In the rocky open fields, however, humans can “sense” in a way that is similar enough to how the lizard senses the environment that they can find the lizards. By being able to find the lizards the assumption is made that we can make sense of, and can understand, they and their world. This concordance of perceptual apparatus is taken to be somewhat resembling a one to one correspondence—so that what the ecologist notices in research correlates with the lizards' presence or actions are taken as direct as opposed to covarying influences. Because differences in perceptual apparatus, perspective, and Umwelt are unaccounted for, there is a tendency to treat the world as independent of the organism, thus a move towards the construction of a transcendental world has occurred.

When the decision is made to go into the field and look for lizards, the mapping of the ecologists' perceptual apparatus onto that of the lizards is first enacted informally, as the ecologist looks for the lizard in some locales in the open, grassy area and not others, and then formally as the lizard that is caught is placed in a net of effects or influences on its' behaviour generated by the features of the environment which are measured by the ecologist.

“Habitat Measuring”.....

Habitat measurement is an important aspect of work at field research sites. In the lizard research various measurable aspects of field sites were recorded, such as distance to forest edge, distance to nearest shrub, size of rock caught under/near, slope of the ground, and temperature under the rock at which the lizard was captured. However, descriptions of

many features of the environment that may be salient to lizards—in contrast to information that can be recorded in a spreadsheet and exported into a statistics package—remain unrecorded⁵¹. No formal or informal record is made of birds flying by, slight breezes, the state of the flowers blooming around the study site (which change markedly over the field season), dew upon the ground, or other such features to which a lizard might attend. Instead, what is recorded is that which is recordable in the sense that can be inscribed on the externalized retina constituted by the ecologist's instruments in a reasonably unequivocal fashion—an accountable and therefore defensible feature to be measured. Most importantly, whatever is chosen to be “data” must first be transcribable to a table and then a spreadsheet so that differences can be tracked. Further, what are recorded are stable features, those that Sam can measure when she returns a week, month, or year later. In this way, the search for stable features in the environment is another way of supporting the quest for the transcendental world. Within this lies a major discontinuity between how the lizard perceives and interacts with the world and how the ecologist perceives the world of the lizards, for the lizard dynamic Umwelt shares little with the measured-as-static world of the ecologist.

The conduct of “habitat measuring” is an important aspect of the fieldwork because it is through these actions that the lifeworld of the lizard is reduced, homogenized, and carried back “into” the field and university laboratories for the structuring of the lizards' world there. The fieldwork during which “habitat measuring” occurs follows the fieldwork during which lizards are sought and caught. The measuring is a type of pulse activity occurring after several days of capturing lizards at a particular site, and is usually conducted as the

⁵¹ Finlayson, A.C. (1995; *Fishing for Truth*. St. John's, Nfld: Institute of Social and Economic Research) argues that one reason that earlier anecdotal evidence for the decline of cod stocks off of Newfoundland were disregarded was because the information was not transferable/transformable into the data recording and analysis tools being used by the biologists.

last activity before a site is abandoned (for a month or so) and the next research area moved on to.

Decisions on which aspects of the lizards' habitat should be "measured" were influenced by a considerable number of factors. Sam first tended to discuss different perspectives on an issue she considered "problematic" with the people around her. These discussions often related to information read in papers, discussions held at conferences⁵² (especially the one from which she had recently returned as GMB joined the field team; which warranted mention at least once a day for several weeks after her return), presentations she had seen at those conferences, and observations she had made in the field. As part of these discussions she polled both the opinions and suggestions of the person(s) with whom she was engaged in conversation. If the issue remained unresolved, then later communication with her spouse (at a remote field site himself) or communication with her advisor contributed to her decision. At a pivotal point a decision was made about which direction to proceed. Occasionally these decisions were long laboured over as they entailed considerable previously unplanned-for effort to be enacted.

It is at this point in enacting a decision about measurement that a considerable abstraction of the lizards' world is developed, because the assumption becomes that what is seen as important by the ecologist in the eventual analysis is also seen and experienced by the lizard to be of importance. In the discussions during which these types of decisions were made, references to the lizard perspective (such as whether distance to the nearest rock is actually something considered, or even consider-able, by a lizard) were notable in

⁵² She discussed information learned in informal discussions at this conference (and others) far more frequently than that learned in formal presentations (discussed more thoroughly in Bowen, G.M. (1999, June). *The "Socialization" and Enculturation of Ecologists: Formal and Informal Influences*. Paper presented at the annual conference of the Canadian Sociology and Anthropology Association - Congress of the Social Sciences and Humanities, Sherbrooke, Quebec.). This may be related to the nature of presentations at many biology conferences where papers are related as 'works-in-progress' as opposed to completed documents. Sam related that such papers are rarely distributed at these conferences as they are, say, at education conferences.

their absence. The perspective taken was that of an omniscient overview of the lizards' world, the view bearing consideration that of the researcher. The "retina" through which the world of the lizard was observed and understood was decidedly human. An examination of several of these field "measures" will highlight the contrast in perspective of the human, and the lizard.

.....and Perspective/Perception.....

Developing an insight that the lizard moves through its world in a certain way, as we could detect and analyze it using various tracking apparatuses, provides us little understanding of how or why that movement occurs. Our being human has embedded within it certain embodied aspects of understanding our human world that are transparent to the point that they are ignored. As an example, when we view the world we do so with retina embedded in a skull generally observing the world from a height of 1.5 to 2 meters above the ground. It is from this vantage that we perceive, interpret, and understand the world, and conclude that it is *the* world. Our gaze falling downward sees the lizard and its environs as it does not see itself. Our gaze at its world glancing out ahead also perceives the world as the lizard cannot—we see it from our perspective, our *point-of-view*, not the lizards.

It is difficult to discuss the concerns of the lizard, the metaphorical *point-of-view*, because there is little to substantiate a claim that we, the authors, understand the lizards' world enough to offer a contrast with the ecologist's understanding. There is however another perspective-based *point-of-view* that can be contrasted with that of the field researcher, the angular perspective of how the lizard observes the world within which it lives. For us to adopt a lizards-eye view, as a start we must lay upon the ground with our head on its side and glance askew.

The world of the "rocky field" is now reduced to a considerably textured world of dark and light, roughness and scattered terrain with fissures

abounding. Limited in visual depth, deeply steeped in incredible complexity and the unknown. The lizard glances forward but a few dozen centimeters, for beyond that the tangle is visually impenetrable. Not living 'over' this part of the world, it is almost living under it now, and actually does so completely at times moving from 'on top' to 'under' this world as the need and whim strikes. Belly against the ground, head under the grass, gazing at pebbles balanced at eye level, the lizard moves within a snarled jungle of vegetation and moguls.

Standing up and glancing down we⁵³ again look at the scattered rocks, tangled grasses, and drifts of wood and other material at our feet. For us to traverse that ground is a matter of a few steps combined with an awareness of all objects that lay in our field of view, to the lizard it is a sojourn into the unknown textures of its world. What for us is mundane to the point of not consciously noticing, to the lizard is immensely complex and unknown. The lizard does not view and walk over that world as we do, but rather travels through it. Thus, to measure the distance to the nearest rock pre-supposes that the lizard has an awareness of the presence of that rock.

Against the view of the land when laying on the ground with the closest eye gazing outwards juxtapose a lizard moving across the field. For us to measure the distance to the nearest rock is unambiguous. Two meters? Just hold the tape measure. Four meters, drape the tape measure over grass, shrubs, other rocks, and fallen logs. Four meters and thirteen centimeters is the measure. Record it in the field book. From our perspective, from our *angle* of view standing vertically beside one rock and looking at the other the distance is unremarkable. The terrain between unremarkable. Un-noted. The distance itself is

⁵³ Whether this "we" is the ecologist, the social scientist, or the reader, is immaterial, for the visual perspective is that adopted by humans, and it is this physical visual perspective being highlighted here.

inscribable, for it cleanly fits into a table and then a spreadsheet. The organic and inorganic clutter between where the lizard was captured and the next nearest rock is, however, unworthy of mention. Unworthy of recording—until perhaps one lays on the ground and tries to observe one location from the other. Then some sense of the lizards' view develops. But this view, the viewpoint of the lizard, is not taken. And so the complexity of its world over four meters is reduced, reduced to being effectively eliminated as the number alone is recorded into a table. The distance fits into the table for analysis, the lizards world does not.

Many other such reductions, simplifications, and other de-complexifications of the lizards world further occur as the habitat is “measured.” Does a lizard discriminate between rocks based on size, especially when madly scrambling to escape a predator? The decision to only “use rocks 10cm in size and above,” “nearest shrubs one meter across at the base,” or rockpiles that are “this big” are decisions based on how *we* perceive the world and the lizard's place in it, as well as based on an idea of measurement embedded in our culture but unlikely to be found in the world of the lizard.

To a lizard, a rock of 20 cm width, one deemed suitable in the research protocols for recording in the table, is useless if one cannot get under it, although it might possibly be useful to scramble behind. A 9-cm rock with a small crevasse between it and the moss beneath into which a lizard can scramble is a potential hiding spot. Lizards react to opportunity, they do not plan. They do not measure. A rock is a rock, or more importantly an opportunity to be utilized to hide, escape detection, or just escape. To a field researcher however, seeing many such “little” rocks (less than 10 cm), as found in many areas of the field sites, means they are hard to categorize and would probably result in irrelevant data incapable of being correlated, related, varied, against any other variable. Smaller and smaller rocks complexify a categorization scheme to the point where it is unworkable, because of their immense numbers. If all lizards were caught within a few decimeters of

small rocks then little is discovered. But, in a co-varying world, excluding small rocks and creating categories of measurement which include the scarcer larger rocks more widely scattered presents the potential for multivariate analysis and significant relationships with other variables chosen using similar boundaries. The lizards' world includes small rocks, with the potential for use by them. By re-formulating the lizards' world to include large rocks as relevant, and small rocks as irrelevant regardless of their potential utility or crevasse offerings, we construct a world for the lizards that is ours, based on our *point-of-view*, not theirs, our requirements for analyzing covariation, not their world. By constructing this world as we do we can then compare one parsing of the environment (rock, irrelevant rock) against another (shrub, irrelevant shrub) in their effect on some dependent variable. Subsequent claims in the research writings about the importance of rock size to lizards neglect to make the distinction between the lizards experience of their world⁵⁴ and the contingencies of analysis and measurement forced upon the researcher in creating that world. Multivariate analysis does not reveal patterns in lizard behavior, the lizards' world, but rather expose decisions made by ecologists in mapping our view of the world onto the lizards' lifeworld.

.....Shaping the Lizards' World as Constructed in the Field Lab

These measures of the environment, viewed to be representative of the lizards' world as they are, are transported back to the field laboratory to construct within its walls a microworld within which the lizards can be placed. These lizard microworlds are constructed with the intent that the important characteristics of the lizards "outside" world continue to exist within the field laboratory. This must occur defensibly to her peers as far

⁵⁴ Scientific writings do not just exclude the agency of the organisms being studied, but also of the humans who engaged in making the decisions in the research. This lack of human agency in scientific writings authorizes both the knowledge claims and research methodologies. See Gross, A. (1996). *The rhetoric of science*. Cambridge, MA: Harvard University Press; Latour, B. (1987). *Science in action: How to follow scientists and engineers through society*. Cambridge, MA: Harvard University Press.

as Sam is concerned, for if there were obvious discrepancies then this would cause the conclusions made from her work to be rejected by others in her discipline. To her, it is vitally important that the visible aspects of the lizards laboratory-based world be attended to and comparable with its “field” world, for this is the only way to defend the overall claims of discovery in the field laboratory as being representative of the lizards’ external world to the broader community of ecologists. Several aspects of the outside world are brought into the field laboratory as some of the research work moves from the field to the field laboratory: habitat is reconstructed as individual enclosures for the lizards; predator avoidance is reconstructed as “sprint speed” down a trough-like track; mate choice and ability to hide from predators is constructed along an index of color and mottling; and, dietary regimes are implemented as consumption of a single species of food—crickets.

LIVING

Within the field lab the ecologist literally “constructs” habitats for the lizards which are perceived as both adequate and, to the necessary degree, representative of the lizards external environment.⁵⁵ Within these enclosures lizards are kept, fed, and monitored. This construction of a “holding” facility for lizards represents the mapping of the humans perceptual apparatus onto that of the lizards to provide “habitat” which overlays that of the outdoors with regards to the lizards experience.

Examining these internal enclosures further reveals which aspects of the lizards environment are considered to be of importance to their survival by the human. Thus, these enclosures allow us to “see” some of the overlap between the humans’ perceptual apparatus and that which is attributed to the lizards. This overlap was specifically thought of in this year of field studies because of the high stillborne rate of infants the previous year, which

⁵⁵ In this, the enclosures constructed for the lizards in the field laboratory become similar to the construction of cages in zoos which (mis)represent the animals in settings of our world, not theirs. See Malamud, R. (1998). *Reading zoos: Representations of animals and captivity*. New York, NY: New York University Press.

Sam concluded was the responsibility of the enclosures she had used. Thus, “enclosures” constructed to the needs of the lizards warranted considerable attention and thus reveal some of the specifics of the environment considered essential to lizard survival⁵⁶.

Lizard enclosures were built in rows on the floor out of rough wood obtained from the discard pile of a lumber mill. They were approximately 30 cm wide, 60 cm long and 16 cm deep. They each had a screened lid recessed into the top of the enclosure which rested on a 2 cm wide wooden lip. Sixty watt incandescent bulbs were suspended over each of the cages approximately 20 cm above the screen.

Each enclosure had clean dirt spread across the bottom to a depth of about 3 cm and 3 rocks, all roughly 15 cm across, were placed in a “pile” under the light to “facilitate basking behaviour.” Crickets were placed in the cage and the lizards could be observed stalking and consuming them. Lights were sometimes turned on and off depending on the cloudiness outside—although this was not strictly adhered to. Water was sprayed using a spritzer bottle into the enclosure every few days, especially when it was raining out side.⁵⁷

Several features of these enclosures warrant consideration. First, these enclosures were a dramatically de-contextualized version of the out door life. The screech of owls, the slither of predatory snakes, the crush of rocks flipped by bears were all absent. In the process of being pursued the lizard also has many options open which facilitate its escape. These “complexities” lizards experience as part of their everyday world are also absent. It is of little wonder that the lizards maximum “sprint speed” (described below) declined with increased time spent in the lab.

⁵⁶ In actuality, stillborne rates were substantially lower in this year after new enclosures were used. In the previous year 30cm by 50 cm tupperware containers (or smaller) with a depth of 10 cm were used.

⁵⁷ For both of these environmental modifications Sam was heard to comment that her intent was to expose the lizards to the same conditions they would experience out of doors. However, despite her stating this several times, there were many other times it was cloudy outdoors that the lights were on, sunny outdoors when lights were off, raining and the cages dry inside, and spritzed when it was sunny and clear.

Unlike lizards, quarks, quasars, mesons, microbes, or plants, do not behave⁵⁸ back at you. The lizard's interaction with the ecologist is one in which each participant is constructed by the other—first in the field where the lizard responds to the ecologist as she was a predator, then in the laboratory enclosures where the reaction is much more benign. Here in the laboratory, the scientist has become an inert part of the lizard's day to which a response is unnecessary. Here again, the interests of the lizard and scientist overlap—each essentially ignoring the other except at critical times of measurement. The enclosures on the floor, with lizards that “bask” on the rocks and under the lightbulbs, are passed back and forth by one, two, three researchers as they walk back and forth in the lab. The lizards, under wire mesh less than half a meter away, do not react. This fits in with the scientists' wishes, for constantly reacting lizards would be of some concern. The two worlds, scientists' laboratory world and lizards' microworld coexist without conflict and seemingly without overlap.

In the laboratory the lizards are still “individuals”, the transformation to generic lizards has not yet occurred⁵⁹, the world of the lizards have not yet undergone that final homogenization into a “report” but are still recognized and dealt with as individual beings. This is unlike the treatment of “subjects” of study in other sciences for physicists generally do not consider single subatomic particles as individuals⁶⁰ nor do botanists construct separate plants as “individuals” in the way biologists do who work closely with animals.

⁵⁸ A distinction needs to be made between “behave” and “react”. Various atomic and sub-atomic particles of interest to physicists (e.g., electrons, photons, etc.) do respond or react to the presence of the research apparatus. “Reacting” differs from “behaviour” in that there are not aspects both of short term change, such as learning, or long term change, such as evolution, which result in changes in the behaviour unlike that which is found in physics. The same classification can also be made along the lines of semiotic behavior (including plants and animals). See Krampen, op. cit. note X, and T. A. Sebeok, “Talking” with animals: Zoosemantics explained. In J. Deely, B. Williams, & F. E. Kruse (Eds.), *Frontiers in semiotics* (Bloomington: Indiana University Press, 1986), 76-82.

⁵⁹ More fully described in Roth, W.-M., & Bowen, G. M. (1999). Digitizing Lizards: The topology of ‘Vision’ in Ecological Fieldwork. *Social Studies of Science*, 29(5), 613-658.

⁶⁰ There have been experiments where individual particles have been trapped and observed in specially constructed magnetic devices.

However, although the lizards have not (yet) been collectivized, their world of activity has been reduced through a series of observations and inscriptional movements into a homogenous and simplified environment going beyond the construction of their enclosures.

RUNNING

In an effort to discern relations between “sprinting” abilities of the lizards and a myriad of other measureable factors (sex, tail length, forearm and hindleg length) the individual lizards were encouraged to run—an outside observer might say were chased—along a 2-metre long, 10cm wide path with a lightly ridged rubber bottom. Such a surface is unlike any the lizards experience in the field itself, for we saw no comparable “open” area in their field environment. Other than the rare expanse of open rock, which offers crevasses and a markedly different purchase for their clawed feet, flat and open areas without cover are nonexistent.

When chased outdoors lizards dash from rock to plant cover to log, frequently freezing without movement when underneath ground objects. In the course of their day escapes from predators which involved short dashes of movement would be the norm—for lizards are rarely chased by predators that can flip over rocks and move their cover thereby exposing them. Other movement through the day, searching for food, mates or escaping smaller aggressors would also involve rapid short dashes or movement under cover from log to rock to shrubbery.

Such natural movements however are incompatible with a scientific, transcendental notion of “speed.” To the lizard, it is not the speed one can attain when avoiding a predator, it is the ability to avoid the predator itself by any ruse—speed, agility, or cleverness—or likely a combination of all of these. Slower lizards may well compensate by being sneakier. However, only one of these aspects influencing “escape” is easily frameable within human constructs of understanding: speed. So it is lizard speed that warrants to be studied

scientifically. “Speed” or velocity is a construct enculcated in North American students early in their school careers, usually in grade 8 or 9: average velocity is the straight line distance an object travels and the time it takes to travel that distance. Although in their world lizards are rarely able to travel in straight-line distances for any length it is not difficult to design an apparatus to test their ability to travel in such a manner—in fact, scientific norms of standardization would require such a test, for the alternatives are unfeasible to measure. By heating lizards to a single temperature (for standardization purposes), laying out a track (such as described above) with a dark pillowcase at the end for the lizard to run towards (the logic being that a lizard will run to a dark area to hide in it) then lizards can be encouraged to run down the track while being timed. In such a manner, repeated racing of the track becomes another standardizing tool that affords calculation of average speed, and therefore correlation to such features as “tail length” or “number of offspring produced.”

It is through the analysis of the average track “speed” of lizards correlated with other measured aspects of the lizard (such as tail length, leg length, or head width) that the lizard and its lifeworld are constructed. If tail length is found to correlate with speed (as reported at a conference), then further inferences can be made about the importance of tail size to lizard survival. If tail size also correlates with the number of offspring borne (as also reported), then further importance can be attached to the importance of the tail, despite the influences of the researcher and her tools on the choice of variables and their operationalization. Covarying exists between the measured variables from which it is concluded that these obviously must be the important variables because they were measured and significantly correlate—ignoring that these variables were initially chosen *because their measures were at hand*. It is this circularity that results in claims of what features of the lizards’ environment (which variables) are important to the lizard, when it is really those that are of importance to the researcher.

HIDING

In their everyday paths, through the scattered world of the field, lizards dart through areas heterogeneous in shade and color. Watching lizards outdoors (and there is little doubt that they spend more time watching us than us them) it can be seen, or rather inferred (for they are rarely actually seen unless out on rocks), that they blend invisibly into the tan, grey, brown and green backdrop against which they live. This type of protective coloration is a form of “hiding” from predators, for if a lizard is invisible, it is a moot question whether its location is in the open or under a rock. It is only when humans violate their environment, flipping over a rock under which they are hiding, that they are noticeable. For a second, both the scientist and the lizard, the predator and the prey, are frozen in time, neither moving. Then, as if by an unspoken cue, the hand of the researcher darts down and the lizard itself accelerates off. It is in the effective coordination of the two protagonists that the “real science” can begin, that the former can begin to “measure” the latter against the instruments of the discipline.

One of these instruments is a Munsell chart,⁶¹ which is used for determining a standardized color and speckling. Originally developed for categorizing soil colors, they are now used extensively by artists, paintmakers, and other professions that need to deal with standardized color. It is the aspect of “standardized” that is important when it comes to using Munsell charts to “measure” lizard color. To standardize methodology is commonplace in science, for it is through these agreed-upon rules of procedure that results can be compared both within and across studies. How this standardization occurs with the lizards is another example of the imposition of anthropomorphic constructs on the world of the lizard.

⁶¹ Use of Munsell colour charts in soil work is described extensively by Latour (1995; *The Pedofil of Boa Vista*, Vol4(1), Common Knowledge) and Goodwin, C. (1996). Practices of color classification. *Ninchi Kagaku (Cognitive Studies: Bulletin of the Japanese Cognitive Science Society)*, 3(2), 62-82. The Munsell charts used in this ecology work had small holes in them (approx 1.5 cm across) over which was a sample of the standardized colour and it's associated code.

To standardize color viewing on the lizards several factors were controlled. Ambient light is controlled and standardized by holding all trials in a white paper lined box with a single light source within which the lizard and Munsell charts could be held. These color comparison charts affords a literal framing⁶² of lizards and their color in a manner such that it later can be inscribed in a table and compared/shared with other lizard researchers who may have used the same scale. The color sample acts as an intermediary between the lizard itself and the number inscribed in a table. The following field note excerpt describes GMB's first observations of color measuring:

Sam then set-up for doing the color analysis of the lizards. Color analysis takes place in a box placed sideways with a clip-on lamp (designed to maintain consistent light for day-to-day consistency) and the color/speckling (she uses 1, 5, 10, 20%) standard sheets being in the box...Sam brings over her first lizard and asks Stephanie to record the numbers she calls out. Sam first calls out a number representing the percent black, and then laboriously examines the lizard against the color standards. Moving the lizard back and forth from hole to hole in the cards (I didn't really understand until I did it) and switching cards back and forth three or four times until she finally announced a number followed by two more representing hue, value, and then chroma based on the closest match to the lizard. She sets out a thermometer on the counter to record the temperature of the room which is done...

⁶² The Munsell chart consists of holes in color patches such that the sample can be viewed surrounded by a reference color. The referent color patches therefore always "frame" the object of interest.

Sams has some concerns about the color of the lizard as affected by dust/dirt after the first one and spends a bit of time wiping it, realizes it's about to shed, and decides that she's going to keep track of shedding schedules to see if that's related to basking and the color. . . . Sam is concerned about the color categorizing being "repeatable" and "consistent" and "without any observer bias on color measure." The percentage dark coverage was okay, but some of doing the color was difficult - you had to be consistent about where you were looking both generally (center back behind the shoulders) and specifically (the outer edges of some scales were more lightly colored) and it seemed that the lizards colors were sometimes between the ones available.

Several features of this exercise distinguish its conduct from the "background" against which lizards themselves or a predator would perceive the color of another lizard. Most notable are: the standardized light from an "natural light" incandescent bulb, the dust removal, and the specific location on the shoulder viewed through the holes in the Munsell chart. Lizards in the real world are dusty, that is an aspect of their lived world. Dust, however, is inconsistent and therefore, in the scientific world, needs to be removed so that standardization can occur. Also, predators also do not focus their eyes merely on a 1-cm wide circle of other lizards backs but on which part of the lizard they catch sight of. The predators or lizards are thus engaged in semiotic behaviour. A lizard predator "reads" the environment and if the lizard provides some contextual clues in the Umwelt of the predator, it is going to be chased and perhaps captured. To counteract this, the lizard has to place itself in its environment in such a way that it becomes difficult to impossible to spot—and thus itself engages in the semiotic behaviour of dissimulation.

These standardizations of measure enacted by the ecologists represent another placing of the perceptual apparatus of our scientific measures on the world of the lizard such that the lizard world is reduced and decomplexified. How we “see” the color of the lizard, mediated by the tools of measurement, the desire for defensible standardized approaches, and the tools into which the values are recorded (tables, spreadsheets) may well provide consistency or inconsistency in the ecologists’ analysis, but is unlikely to have much overlap with how a predator or lizard perceives another lizard.

EATING

Feeding occurred every two to four days, although this changed over the duration of time in the field, ostensibly for reasons related to the lizards’ needs. After several weeks of feeding the lizards every two days, a visiting researcher related that her own collection⁶³ of lizards needed much less frequent feeding. Subsequently, Sam also reduced feeding frequency. However, our field observations suggest that the time commitment involved with feeding the ever larger number of lizards was also a factor that mitigated the decision. As the season progressed, and the number of captive lizards increased, Sam was more frequently commenting on the time it took to feed the lizards and, only being half-way through the field season, was concerned about the time commitment.

Body mass was measured weekly and this information was used to triangulate food consumption. Although there was a count of crickets in each feeding period allowing the lizards’ consumption to be monitored, crickets were also notorious “escape artists” and it was recognized that this did not necessarily give a clear indication of consumption. By monitoring body mass changes, our ecologists determined whether a lizard’s dietary needs

⁶³ Many herpetologists are “collectors” of a broad range of organisms in their study category. A herpetologist who studies rattlesnakes may have collections (even at home) of dozens of different types of snakes. It is perhaps important to note that the captive lizards and the field laboratory were all pregnant, and thus perhaps not comparable to those of the visiting researcher.

were met. The lizard mass measurements also mediated decisions regarding when to enact field site visits, such as in late afternoon to return male lizards to the site of their capture.

The lizards' diet is another example of the de-complexifying of the lizard world in two ways. First, lizards now had a vastly restricted area (their enclosures) in which to "hunt" the crickets. Due to the size of the enclosures, the crickets had many fewer avenues of escape. Secondly, the lizards were restricted to a cricket diet from their ordinary varied selection of small (~one-centimetre long) invertebrates. This "adequacy" of the crickets for the lizards is another human interpretation of the lizard Umwelt, a decision mediated by the availability of crickets at a nearby pet store. This standardization of individual crickets as the unit of analysis for consumption (lizard dietary consumptions were counted as 'one cricket, two cricket...') of monitoring of lizard dietary consumption had aspects of variation which were unconsidered. The nutritional value of individual crickets varied widely both observably in their size, in which considerable variation existed, but also in their own internal state—how recently had a cricket itself eaten? Thus, the crickets became homogeneous units of analysis in the dietary world constructed for the lizard.

DISCUSSION

In the social sciences there exists a considerable debate whether the categories chosen by researchers are appropriate for understanding the world of the individuals and their communities. Structuralist approaches are often critiqued for their insensitivity to the characteristic concerns, understandings, and worldviews of the people whose behavior is to be explained. Behavioral ecology is a science concerned with understanding the natural history and behavior of organisms as part of their role in specific ecological settings. In this paper, we argue that in a similar fashion to structuralist analyses of human behavior, behavioral ecologists construct their categories in decidedly anthropocentric terms. In both the field setting and the field laboratory the lifeworld of the lizard is shaped so that it conforms to the perceptual lens of the discipline and its measurement tools. In their

everyday research work, field biologists attempt to construct lizards and their environment as transcendental objects. However, this transcendental world is not truly transcendental, but rather thoroughly anthropomorphic in that it topicalizes features and perspectives salient in a human world, not those of the lizards, the birds of prey who consume them, or other inhabitants of that world. The world of concepts into which the lizards are constructed is a world that is independent of local constraints. Scientists' attempts in arriving at a world independent of local particulars leads to practices in which they de-complexify and homogenize the world of the lizards (and its parts); cleaning the lizards, chasing them through channels with rubber tracks that don't exist in their own worlds, bringing them to the same temperature, etc.

As a result, scientists concerned with the behavior and natural history of animal species map their animal species against the Procrustean beds of human categories. For example, the characteristics of lizards' field habitats were construed by the ecologists we studied in terms of the distances to the closest rocks, bushes, trees, and forest boundaries. However, one may question whether these categories are relevant from the perspective of lizards, their Umwelt. For example, a forest boundary at a distance of 25 meters may far exceed any habitat size that is exploited by the lizard. Human categories also influenced in significant ways the design of the "miniature habitats" that were constructed in the field laboratory as holding areas and to study captured animals. From these interior-ized "worlds" much insight is gained into the homogenization and decomplexification of the lizards' world occurring through the investigative moves and then conclusions of field researchers. So what field biologists measure and study may be completely irrelevant to the lizard, or framed in such a way that it reifies characteristics salient in human Umwelts, such as "forest edge," but whose choice now suggests that this feature is a factor that needs to be considered. By choosing variables for measure based on our view of the world, we make claims about those measures which may be irrelevant to the lizards in the first place. If there

is a statistically significant relationship between behaviour and distance to the forest edge, then ecologists construct the relationship as something significant, if there is no relationship then it is constructed as a relationship that is not significant. What is never questioned, once a variable such as forest edge is “identified,” is whether the variable being considered is even salient in the lizards’ world. The meaning we attribute to the world is no doubt “real” to us, but this reconstitution has little to do with the world of the animal. This is not to suggest that as researchers we can ever completely adopt the lifeworld perspective of the animals we study, but not even considering the tension between our choices and their lifeworld consigns us to unreflectively making choices that are quite experience-distant to the animal.

The activities of the field researchers and their activities in the lab, as they attempt to construct a transcendental world within which they intend to place lizards, demonstrates that conducting research with animals that have a sense of the world themselves is a different activity than that conducted by other scientists, such as physicists, who are trying to understand the phenomena in the world. Figure 1a diagrammatically illustrates the view of natural phenomenon that scientists studying non-sentient phenomena construct in attempting to understand those phenomena. However, to study organisms which themselves have a sense of the world, to understand their Umwelt as von Uexküll⁶⁴ advocates, biologists would need to construct an understanding such that the agency of the lizards in the world was accounted for (such as depicted in Figure 1b). Understanding an organism’s place in the environment is as much about understanding the perception of that organism in its environment and its reactions to those perceptions as it is understanding the phenomena which constitute that organism’s world. It is an attempt to understand dynamic interactions, because the lizards are responding to the researchers’ presence in the field just

⁶⁴ von Uexküll, J. (1973). *Theoretische biologie* [Theoretical biology]. Frankfurt: Suhrkamp. (First published in 1928).

as much as the researchers are responding to the lizards. However, what is illustrated in this paper is that there is little difference in how ecologists construct the world and the way that Figure 1a depicts the world is constructed by physical scientists such as physicists and chemists.

[Insert Figure 1 about here]

The reductionism which occurs in the practice of ecology research dramatically de-complexifies the world of the organisms being studied, and in part this is mediated by the tools available to perceive their environment. With the hymenoptera (e.g., the bumblebee), we developed a better sense of their world as tools were developed which more closely emulated the bees perceptual framework. At what point did we know we were not seeing the world as the bee did?—when we developed equipment ourselves to perceive UV and Polarized light. Until the development of those tools we did not know we did not perceive the bees world as they did, and hence did not know we should not be trying to. Thus, in this study we demonstrate that ecologists do not know which aspects of the lizard world are accurately understood and, despite all of the mediations of research design and analysis, assume we experience the world in the same fashion as they do. Only new perceptual tools will allow us to recognize any folly in this view(ing) of the world.

Understanding how the field of ecology constructs knowledge claims and research methods has significant implications for policy development on environmental issues. By understanding that ecologists (and we as a society) construct an anthropocentric lifeworld for organisms, we can better understand how to deal with environmental and political problems such as commercial extinction of species such as cod, species extinction, and conflicts between different managed and commercially-exploited resources (e.g., the interests of forest and salmon industries may be different in that logging practices destroy salmon spawning grounds). However, to address this issue a better understanding of the enculturation process of ecologists (and students in general) is necessary. It is not that

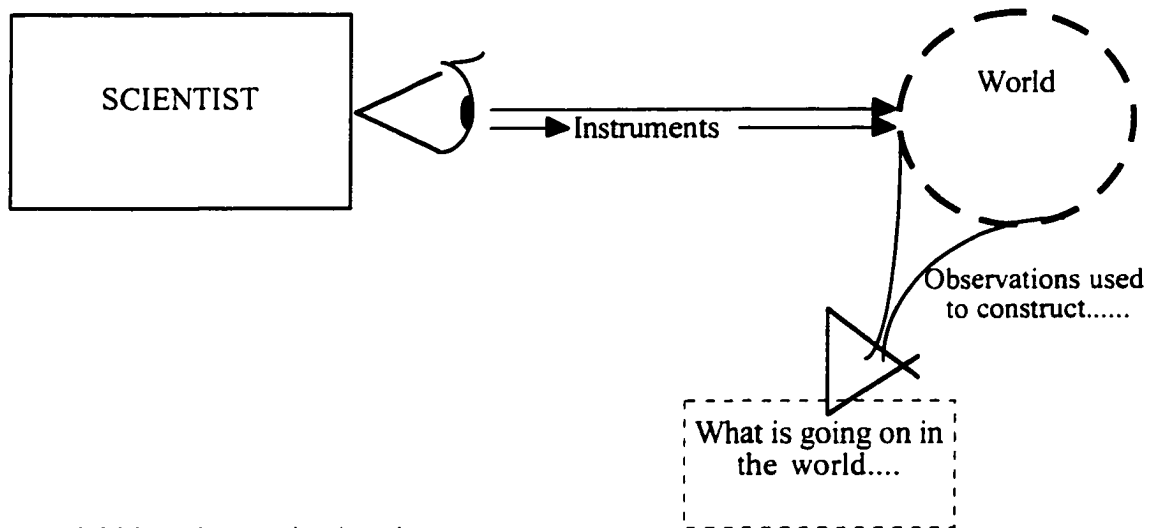
ecologists do not develop a sense of connectedness to their organisms, for this lizard ecologist clearly did—and it is argued that developing “a feeling for the organism” is a common experience of scientists⁶⁵. However, what we have argued is that the tools with which the environment of the lizard is perceived are applied in a manner that is considered unproblematic—and this seems to be little reflected upon. In part this might arise because undergraduate ecology courses, unlike those of the physical sciences, are taught in settings⁶⁶ which are quite unlike those at which the research is actually conducted. More importantly, however, is that it is rare that these educational settings actually contain any non-human living organisms that students engage with for any length of time—there is little opportunity in a four year degree to gain any experience in understanding the perspective of the organism being studied. Although it is not possible to say that if the concerns, issues, and practices of ecology were taught along with prolonged engagement with live organisms that ecologists would more consciously try to understand the worldview of the organisms they were studying. However, it is clear that one consequence of not engaging with animals for any length of time in undergraduate study is the placing of an anthropocentric worldview over that of the worldview of the animals.

⁶⁵ Gould, S.J. (1984, March 26). *New York Review*.

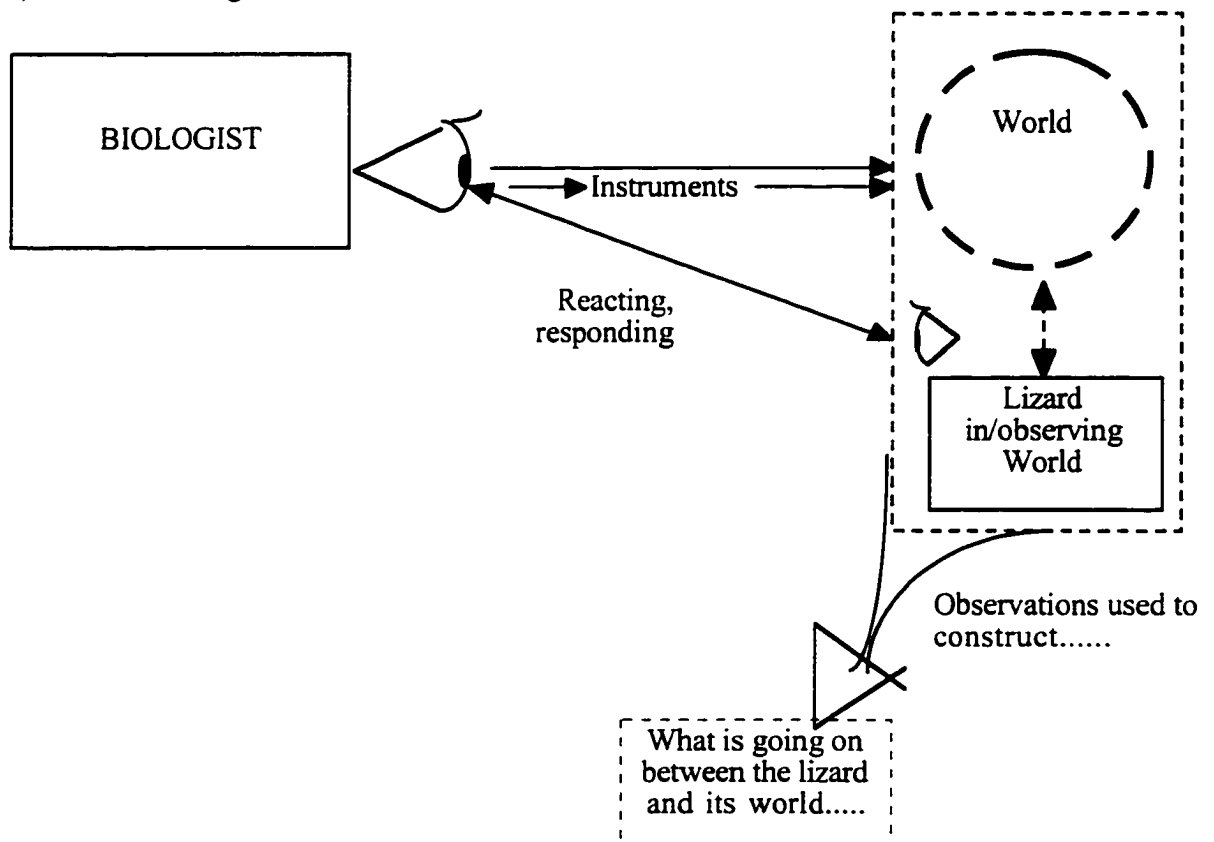
⁶⁶ We have conducted a four month classroom ethnography in a second year university ecology course, participated with undergraduate students in field research activities for their courses, and conducted numerous interviews with students and graduates of science programs.

Figure 1. Diagrammatic representations of (a) physicists or chemists viewing their research world contrasted with (b) a biologist understanding an organism in its lifeworld.

A) Laboratory-based, non-organismic science



B) Field-based, organismic science



Chapter 9:

The roles of stories in communities of ecologists

The roles of stories in communities of ecologists

Abstract

A 'community of practice' in science is composed of more than the scientific practices, knowledge, and linguistic and material concerns of the members of the community. Yet, discussions of the components of social practice which constitute a domain often only focus on the socially-mediated influences directly affecting knowledge claims, but pay less attention to other informal interactions which are important to the 'community' while playing a lessor role in the development of knowledge claims. One such interaction, related to both developing knowledge claims and social structure of the community, is the telling of "stories." Individuals who have engaged in field research practices have a host of experiential stories upon which they draw to help develop their understanding of research situations and which help form the social bonds of the community. Results from a three-year ethnography with ecologists in their field, laboratory, classroom, and 'leisure' settings are analyzed to examine the roles that stories play in the interactions of ecologists and the structuring of their 'community of practice.' Implications are drawn from those interactions for how we structure and conduct science classes in public schools.

Sociology of science studies most often examine the formal ‘texts’ of science and the formal settings in which those texts are developed and used, such as interactions between scientists in laboratories and at conferences. Rarely are the social interactions of scientists ‘away from the lab’ studied, despite the importance of these settings for community social cohesion and the contributions they can make to the conduct of research. Our (implicit) cultural knowledge of the formal(ized) processes of science often results in science being taught in schools as if the formal texts of science are the only way to understand the process of science—resulting in school curricula which reflect various formulations of “scientific method” or the fragmenting of science practices into “science process skills” (e.g., AAAS, 1989). Recently, understanding of the socially-mediated aspects of scientific enterprise gained from ethnographic research (e.g., Lynch, 1985; Latour & Woolgar, 1986; Traweek, 1988) has led to a critique of these culturally-held perspectives on the conduct of science concluding that they are inadequate representations of the conduct of science and are therefore inadequate foundations upon which to structure science education practices (e.g., Duschl, 1990; Brookhart-Costa, 1993; Roth, 1995). This critique, in part, suggests that the scientific (research) practices and knowledge taught to students in school settings under-represent recent understandings of the socially-mediated decision making and knowledge construction practices occurring in science.

Social studies of science research from which suggestions for classroom approaches to teaching science are drawn (Bowen & Roth, 1997; Roth & McGinn, 1997; Roth, McGinn, & Bowen, 1996), often present scientific discovery and “fact-making” as being affected by socially-mediated and derived processes. However, the studies from which these suggestions derive usually focus on the “formal” aspects of interactions between scientists (such as the “shop talk” reported on by Lynch, 1985) and not on informal interactions. This has occurred in part because social studies of scientists have occurred in formal laboratory settings and because the research has deliberately avoided the “gossip and

scandal” of science (Latour & Woolgar, 1986; p.32) which removes these studies from the “story” aspect of informal scientific exchange as it occurs between scientists such as ecologists. Thus, suggestions for classroom practice from ethnographic studies of scientists are drawn from what are essentially social studies of scientific knowledge—or how knowledge is constructed in scientific communities—but draw little on sociological or anthropological studies of science as a community which would reflect how the social communities⁶⁷ themselves are constituted.

It is possible that sociological studies of science disregard the importance of ‘leisure’ discourse in science communities because of the assumption that scientific communities are fundamentally similar. However, some research communities are differently structured than those which are traditionally studied (i.e., chemistry, physics, and other laboratory based sciences) and exchange information in different ways. Ethnographic studies of the fieldwork of biologists are only infrequently conducted (e.g., Nutch, 1996) and I will argue that the structure of these field research communities and their resulting social interactions differ from those of the research laboratories in which sociological studies are often conducted. From an educational perspective, ethnographic studies of field ecologists in their research settings may contribute more insights for classroom practices than do studies in PCR (e.g., Rabinow, 1996), TEA laser (e.g., Collins, 1982), or particle accelerator (e.g., Traweek, 1988) facilities because of the relative commonality of local resources and community structures available to a classroom teacher and those utilized by an ecologist in fieldwork (i.e., a woodlot or hillside, and measuring tape, thermometer, and compass).

⁶⁷ To be distinct from “communities of practice” as described by Lave & Wenger, 1991. In this I am making a distinction between the aspects of community which revolve around the concerns, practices, and tools of a discipline and which are central to the development of knowledge claims and the social interactions which contribute to the social structure of a community.

This paper extends the work of those earlier papers which made suggestions for classroom practices by taking an anthropological stance to the ethnographic work conducted with ecologists in examining how informal conversations contribute to the forming of a science “community” and how better understanding these might inform our teaching of science. Sharon Traweek (who has spent over fifteen years studying particle physicists and makes a distinction between her being an anthropologist of science as opposed to being a sociologist) defines a community as “a group of people with a shared past, with ways of recognizing and displaying their differences from other groups, and expectations for a shared future” (Traweek, 1992). Her definition goes beyond the framework of examining the specific science domain-related socially-mediated concerns, methods, interpretive practices, and history of a discipline which leads to the construction of knowledge claims and includes the social aspects which emphasize the “community” aspect of “communities of practice.” Her approach informs this work with ecologists.

Ethnographic research with Mayan midwives reported that stories played a major role in decision-making with resulting implications for what and how newcomers learn (Jordan, 1989). Storytelling also plays a central role in learning about copier machine repair work in which “old-timers” related to each other “war stories” about past experiences in making repairs which subsequently play a vital role in diagnosing and carrying out new repairs (Orr, 1990). In a similar way, to help solve problems clients are having with using software, software support persons build up coherent stories that relate closely to other, more familiar stories. By manipulating the story plot—proposing a ‘work around’ based on these stories—the support person could bring the living narrative of an ongoing problem to a satisfactory conclusion (Pentland, 1997). Narrative discussions amongst “new” doctors in the formalized situation of being “on rounds” are central to making effective medical diagnoses and the construction of these narratives depends on experience in accumulating and building these narratives (Cicourel, 1990). Novices take more time collecting

information and telling it and part of becoming enculturated into the discipline of being a medical diagnostician is learning what the important part of the patients story to relate to other doctors is and which may be left out. Participating in these group discussions helps the novices “shape” their storytelling so it conforms to the discourse of the “old-timers.”

In all of these disciplines stories implicitly communicate, to both old-timers and newcomers, how to conduct problem-solving in the domain (such as repairing a copier, assisting a birth, solving a software problem, or diagnosing an illness) and help newcomers learn the skills of “war story” telling, through which they become legitimate participants in the community of practice. If we accept that becoming a field ecologist is a type of apprenticeship, then just as with Mayan midwives whose learning was supported by conversations and stories about problematic and especially difficult cases, so too might such much learning occur through storytelling in ecology.

Purpose: Stories and Ecologists

Stories play many roles in the community of ecologists ranging from diagnosing a research problem to teaching domain specific discourse to newcomers. Learning *to* talk, using both formal discourse (about theory, formal presentations at conferences, etc.) and informal narrative (through storytelling) is a key part of becoming a member of the community of ecologists. It is through both of these types of discourse that membership in the community is negotiated and determined and by acquiring the discourse through participation newcomers proceed on a trajectory towards becoming old-timers.

Becoming a member of a community which engages in a particular domain of inquiry involves more than merely acquiring a knowledge base about that domain—there exists both the body of facts and also the field practices from which those claims are derived. However, discussions of social practice in science often focus on the social aspects that affect the former (i.e., social mediation of knowledge claims) and not those that affect the latter (i.e., practices), and spend little time on the other purposes of such discussions. In

ecology, individuals who have engaged in field research practices have a host of stories about those experiences upon which they draw to help develop their understanding of potential research situations, and which help develop the social bonds of the community. In this paper, I examine the many roles that anecdotes or stories play in the community of ecologists (and those studying ecology).

Theoretical Commitments

Science as Social Practice

The theoretical approach used in our work studying science in schools, university, and professional practice⁶⁸ is informed by the emergence of anthropological, ethnomethodological, and sociological studies of scientists at work (Latour & Woolgar, 1986; Lynch, 1985; Traweek, 1988). In contrast with the more traditional work on science that saw in scientists a special breed of people who use special skills and procedures to cull facts from nature, all of the cited studies take a common perspective of science as a set of practices that are shared by the members of specific communities. From this perspective, knowledge is not something residing exclusively in the heads of people, but to a large extent is constituted by the ways people (scientists) go about their daily business, how they justify what they do, the stories they tell, and so on.

During work in a university ecology classroom and in interviews with practicing scientists and students in which we were studying the use of representations in scientific work, we recognized that the “stories” being told were a necessary component in the reflexive interpretation of graphs (Bowen, Roth, & McGinn, in press). They also appeared to serve an important function in the community of field ecologists contributing to the

⁶⁸ The research group within which I participate is one of the few that conducts studies both in institutions of learning (elementary, middle, and high school, and university) and in professional practice which allows us to engage in cross-community ethnography (Guba & Lincoln, 1989) and dis/confirmation of findings across communities.

conduct of field practices, discussion of ecological theory, and defining of the community's membership.

Stories

The word “story” can be interpreted to have multiple meanings, and there are specific senses that are not included in how it is used in this current analysis. This paper does not discuss stories in the sense of multiply authored narratives which “aim[s] to push the story line in different directions” thereby constructing the claims of specific domains of science as do some authors (Rouse, 1996) or the formal “stories” in work settings reported by others (e.g., Lynch, 1985) but focuses on exchanges in informal, leisure settings between members of the same community (such as the “war stories” reported on for photocopier repair technicians (Orr, 1990), although there are some differences). Thus, this relation of stories is not about those stories which represent the grand narratives of scientific claims such as recounted in science (text)books, but is instead a focus on the anecdotal narratives exchanged in informal conversation between people with some common social connection in their domain of science research.

What I consider to be a “story” for this paper can be as brief as two sentences made as casual, off-handed, comments in an initial meeting between two people or a lengthy narrative explicitly presented as a story by a member of a group to other members. I view a “story” as a text which is an “emplotted” narrative offered in informal-setting interactions—essentially Polkinghorne’s (1995) use of the term story in the general sense of referring to “narratives that combine a succession of incidents into a unified episode” (p. 7) whose subject matter is human action. Further, the view that “Stories are a way of packaging experience” (Shuman, 1986; p. 20) informs my perspective of storytelling as part of the discussions in which we all engage when interacting with others about our experiences.

Stories endure because they relate personal experiences, often reflect considerable emotional involvement, and are enduring for that very reason (Emihovich, 1995) and when they are exchanged between scientists discussing the conduct of their work they belie the stereotyped image of the impartial, unemotional, objective scientist. This does not mean, however, that the conceptual or informational content of the story lies beyond the ground of reason (see Emihovich, 1995), as many authors argue. This paper is, in part, a deliberate attempt to challenge our “cultural tendency to value formal, theoretical knowledge over the contextual knowledge derived from everyday practice” (Nelsen, 1997). In fact, experiential stories can be very revealing of what the conduct of research is actually like, which is of particular use to newcomers. In the informal atmosphere of chatting over the day’s fieldwork—over a beer in the bar, or during lunch in the field—when examining the acceptance of newcomers, story-telling can be examined as an aspect of “impression management” (Goffman, 1959) in which newcomers and oldtimers construct a role for themselves which corresponds and “fits with” those of the others with which they are involved.

The situations in which the social interactions used in this paper occurred involved the entire range of participants in ecology from those with doctorates and extensive field experience to enthusiastic amateurs just beginning to work in the field. Thus, the “stories” from which the claims in this paper are drawn relate situations in which field workers participate, observations field workers made, conversations ecologists had with other ecologists and non-ecologists, and even stories which were related “second-hand.”

Data Sources

This paper draws mainly on overlapping ethnographic studies of “student” and professional ecologists conducted over three years at three institutions. In this time I participated and interacted with ecologists from different sub-disciplines (and with different theoretical interests) in several different ways: (i) as a field assistant with ecologists at a

remote field site, (ii) attending (and recording) presentations at conferences, symposia, and departmental gatherings, (iii) socializing “after hours” with groups of under/graduate students, post doctoral “fellows,” and university professors, (iv) conducting over two dozen semi-structured interviews (with both ecologists and non-ecologists) during which they interpreted (their own and other) scientific inscriptions, and (v) conducting a video ethnography over four months in a second-year university ecology class. In addition this paper draws on work with grade eight students as they conducted field projects (see Roth & Bowen, 1993, 1994, 1995; Roth, 1996a), and that with B.Sc. graduates as they engaged in similar field work (Bowen & Roth, 1998), and with second year ecology students as they engaged in a field research exercise. The database from this study was composed of (i) transcribed audio- and videotaped records of interviews, discussions, and field research practices, (ii) field and reflective notes of the daily practices I engaged in as I participated in field activities with ecologists and interacted with them at other times, (iii) annotated digital photographs of field and conference activities, and (iv) written artifacts produced by the participants in support of their work. I also draw autobiographically on my experiences as a field ecology researcher in the mid-1980’s.⁶⁹

For analysis, members of the research group with which I participate independently reviewed the database and we independently constructed our individual insights and analyses. We then reviewed the data sources together to conduct collective interaction analysis during which we discussed and resolved the contradictions in our personal

⁶⁹ One of the (traditional) tenets of anthropological work is that one not start from the perspective of being a “native” and so my academic/research background warrants mention. I have an undergraduate degree in biology, a Masters in toxicology, and have worked as a researcher or assistant on numerous field-based research projects in the past. However, sociologists of science are often encouraged to obtain advanced degrees in the science area in which they are studying (Traweek, 1992) and auto-ethnography is becoming more common (see Barrett who studied the town he grew up in (1996) and Orr studying photocopier repair technicians (1990)). Constant communication (and reflection) of field notes and digital photographs using e-mail between members of our research group (some of whom are “natives” to ecology and others who are not) enhanced my non-native interpretive stance as the comments returned to me re-focused the observations and interpretations I was making so that the familiar became strange and I could describe and study it from that perspective.

constructions and assertions. We reviewed other sections of the database to check the degree to which it confirmed or disconfirmed our claims, reformulating them until they were representative of the data. Our analysis throughout these steps were grounded in interaction analysis (Jordan & Henderson, 1995) and in the hermeneutics (Guba & Lincoln, 1989) and semiotics (Bacide, 1990) of scientific texts. My claims about the roles of stories in the community of ecologists were then discussed with a number of ecologists to determine whether they were credible within the community of ecologists. Repeatedly, discussing the role of stories with ecologists elicited comments on the importance that anecdotal stories played in their own work.

Discussion of Findings

The fieldwork conducted amongst ecologists led me to conclude that field ecology differs in substantial ways from many of the other sites at which sociology of science studies have been conducted. This has several implications, particularly with regards to how the community is structured and how new members are enculturated into it; both of which stories play a critical role in. Before discussing the role that stories play in the field of ecology, I'll briefly discuss some of the fundamental differences between the practice of ecology research and other domains (notably laboratory settings) so that the importance of stories to ecologists is more apparent.

Ecology Research Differs from Other Domains

Location

Unlike many of the disciplines in which science studies have been conducted, the locations at which ecologists conduct research are not found in the few uniquely constructed, human-designed areas (called laboratories) in which physics and chemistry research is conducted. The laboratories considered most important in the physics and chemistry research communities are widely known or can be easily determined by

examining recent publications in the literature; in part because the lag between completing research and publishing it is so short (as described by Traweek, 1988). This differs substantially from the research “worlds” of an ecologist, which are widely dispersed. In many ways the ecologists research “world” starts when they walk through a door into the outdoors and the location(s) at which important work is being done are not possible to pinpoint. Although ecologists often have specific research interests dealing with specific organisms, the ecological interactions that inform the questions an ecologist may ask can occur almost anywhere—research being conducted out of a single ecology “lab”⁷⁰ at a university may be occurring anywhere in the world (it is not unusual for researchers based out of a single lab to be working on several of the continents for instance). In this, ecology is fundamentally different from the laboratory-based research sciences for the domain of laboratory scientists is found as they walk into a specific building, for field ecologists their research domain is found as they walk out of a specific building into the rest of the world.

Member Resources

The locale of the research has considerable consequence for the interactions within the community. In many disciplines, especially technologically grounded ones such as physics, scientists work in close contact with each other on a day-to-day basis. Clusters of highly educated and experienced researchers are present at most research sites (e.g., Traweek’s high energy physicists (1988), Carlone’s chemists (1998)) who constantly focus other members’ research, questions, and interpretive frameworks either implicitly or explicitly. Ecology research can occur in large groups of people in the field (e.g., Latour, 1995) using considerable technical equipment. However, it is just as likely to be conducted

⁷⁰ The “lab” is how ecologists refer to the equipment-rich areas, which may be in a university building, a construction trailer in a remote location, or in the back of a van, at which they conduct measurement activities that may be difficult or impossible in the field. “Equipment-rich” is also a relative term compared to physics research—it may be as simple as a light meter or an electric balance shielded from the wind. In the spirit of ecologists discourse practices, I’ll use their term “lab” instead of the more formally expected “laboratory” for the remainder of this paper.

by a single person in areas of remote isolation, varying from spending three months in a trailer in a remote area of Northern Ontario studying wood turtles with only a few visitors to provide company, to two months spent in isolation while hiking through the jungles of Borneo studying Orangutans and living alone in a field camp.

This diffusion of research sites means that the supervisory structure that exists in laboratory based research is not present in the same way in ecology research. In laboratory-based research there are often various “oldtimers” (in this sense, used to describe any individual with more experience—ranging from doctoral students to professors) supervising the everyday work of others in the laboratory. In field ecology research there are often few “old timers” present when a researcher is conducting research, other than other graduate students who themselves are at varying levels of experience and who may be conducting their first independent⁷¹ research project. In essence, the strong supervisory structure of newcomers which exists in laboratory-based sciences (Traweek, 1988; Carlone, 1998) or medicine where “decisions must be directly or indirectly monitored; designated experts must be aware of their activities” and where the novice is “subject to constant tacit and formal scrutiny” (Cicourel, 1990) does not exist in ecology field research. This is particularly true in the “field” component where supervision (and therefore feedback on methodology) can be temporally and physically quite removed from the actual conduct of field research.

Text Resources

Apart from the conceptual feedback received in the laboratory-based sciences from other (senior) community members, there is also a considerable difference in the written texts available to guide research. In the laboratory sciences, if nobody in your local community can answer a question about your research a wide variety of text resources

⁷¹ Having volunteered or worked on the projects of others is not unusual.

(journals, textbooks, etc.) exist in both the laboratory itself and, failing that, in the university library. The situation is different for ecologists. While in the field conducting research ecologists have few written resources to rely on; neither many textbooks nor journals are available and libraries may be far distant. This problem is more acute the more remote ones research site is. Thus, ecologists are considerably dependent on prior knowledge, creativity, and visitors who ‘pass through’ their research site. These ‘visitors’ are present on almost all field projects (with exceptions in Antarctica, etc.). Ecologists who have conducted research in remote areas often relate stories of other ecologists or undergraduates ‘dropping by’ because they heard that someone was in the area conducting research. Even local community members offer to assist in fieldwork and their opinions about methods are also solicited⁷²—in social settings non-ecologists can have as many stories about field experiences as do the ecologists. The stories from locals and itinerant (student) ecologists act as a valuable resource for the fieldwork that is being conducted.

Non-Member Resources

The differences between field and laboratory research sciences have consequences for how membership of the “community” is constructed. Unlike particle physics where participation in the research comes from many years of enculturation through formal academic participation (Traweek, 1988), field-based research such as ecology has many enthusiastic, interested, “amateurs” who assist in field work projects⁷³. Often, these “amateurs” possess considerable experience and aptitude in fieldwork having participated in

⁷² Unlike many of the laboratory sciences, which require specialized observational knowledge and equipment, the local ecological lore can be quite valuable to an ecologist and this is often related in stories by locals in informal settings. That non-ecologists can offer valuable insights is another difference with the laboratory sciences.

⁷³ Archaeology and geology are also disciplines that have a considerable number of “amateurs” who assist in the field research work. In the sense that I use the term “amateur” I refer to people who have no initial academic background in the discipline but participate in field research in collecting data. I use the term “newcomer” to describe those who are academically pursuing that discipline but are inexperienced in field research.

projects year after year, and they often offer considerable expertise and insight⁷⁴ to those conducting the field research. Thus, volunteer helpers on projects can be resources of substantial use to the field researcher and the stories they relate about other projects on which they have worked can offer valuable insights. However, this can also mean that there is little scaffolding of graduate students to improve research practices because those conducting the field research, even if in charge of other individuals who are working as field assistants, are often relative “newcomers” themselves to field-based research.

Stories and communities of ecologists

During the hours following ecology field and lab work, “storytelling” was a commonplace occurrence involving participants from a wide variety of backgrounds. In these settings stories were a predominant part of conversations, permeated discussions within and among groups of ecologists, and served many roles.⁷⁵ Stories were clearly important for newcomers to ecology research (senior undergraduates, MSc students) for learning subject-specific discourses and field research practices [which are poorly communicated in the formal aspects of their education. See Bowen (1999) for a discussion of this in detail]. Of more importance in this paper are the roles stories serve in the community of ecologists including contributing to understanding of theory, suggesting directions and methodologies for research, providing information on the organisms and terminologies, and establishing membership and status in the community.

⁷⁴ Over many years of observations of field research I have seen nurses, construction workers, teachers, actresses, and homemakers actively participate in data collection in field research. Sometimes their expertise is such that they have worked to “clean-up” the research of undergraduate field assistants whose work was deemed unsuitable for recording by the principal researcher. These “amateurs” can also play an instructional role with “newcomers.”

⁷⁵ Parsing of the roles of stories into different categories is, of course, entirely artificial and done for discursive reasons. not because the categories are necessarily observable in that sense in any individual story or specific setting. As a result of this artificial parsing, categories are not mutually exclusive but overlap.

1. Theory

For the most part, ecology does not have “theory” as in the physical sciences, so use of the term should not be considered as it would be for the physical sciences. However, the term is often used in ecology to describe general claims about “competition,” “predator/prey relationships” and other cornerstones of discussion about ecological relationships. Theories of this sort were rarely discussed explicitly by ecologists either in the field or in the lab. More often, narratives about the ecologists’ experiences in the field had theoretical perspectives implicitly embedded in them. Although narratives provide information about practices in the field and interpretation of data, they also act as a resource for ecological theory. For instance, in a social gathering after a conference, one field ecologist related a story (over several minutes) of how on moonless nights when he was doing research work in a stream he could reach down and “pet” salmon that were hanging motionless in the stream. He said he suspected this was because there was phosphorescence in the water and that the salmon were staying so still so that their predators, grizzly bears and seals, could not see them and catch them—they were obviously outlined by glowing light if they moved. Another ecologist related a story in return about harbor porpoises on the east coast which were observed (using radio tracking devices) to not move at all on some nights and which, in captivity, were subsequently seen to not move at times when the water was phosphorescent. The story related that the researchers on the porpoise project concluded that the porpoises were holding still so that their predators, sharks, could not see them in the water. Thus, a ‘field idea’ held independently by two groups of researchers based on field observations (of the type they refer to as “anecdotal”—which are not reported in the literature) gained additional credibility because of correlating observations in other species thereby re-ifying theories about predator-prey relationships through the relating of the two stories. In this example, as well as many others (such as when a story is used to inform

field practices), theory was discussed not explicitly but implicitly through examples related in stories of field research experiences rather than explicitly.

2. New Directions for Research

Stories related casually between ecology researchers can play an important role in causing a researcher to re-frame a problem. In informal settings, stories are often related between ecologists even when there seems to be no immediate link between what the story is about and what the listener is conducting research on. In some cases it is merely a matter of better understanding the field of ecology, but in other circumstances stories can cause one to re-frame and reassess the entire approach one is using on a project. An ecologist working on a stream reclamation project related the following narrative when she heard that I was looking at the role that stories played amongst ecologists:

I'm just starting to realize how important anecdotal stories are to the research we're conducting and how we're thinking about Hogan Creek. The other day [a local] was talking to us about Dark Bay and saying that he thought that one reason that there was hardly any life in it any more was because everything in it was starving. That got us thinking about the role that Hogan Creek played, since it flows into the bay, and that maybe we had to start thinking about what we were monitoring in the creek differently. We have been looking at it only from the perspective of levels we had to maintain in it for the creek itself to be minimally healthy. Now we're thinking about it from the perspective of not only what the creek needs to be healthy, but also about what needs to be flowing out of the creek for the organisms in Dark Bay to be healthy too, because they rely on nutrients coming from the creek.

The conceptualization of this stream reclamation project was re-constructed so that it now included the broader perspective of the effect the creek had on the bay into which it was flowing. Although there is undoubtedly some evaluation of the quality of the

information in the decision as to whether the information should be heeded, this does not actually have to be the case—because stories can shift perspective whether they are accurate or not. In the above example it matters little whether the organisms in the bay are actually starving or not, what is central is that ecologists working in the watershed had not previously considered outflow effects and this perspective is now included as part of the conceptual framework of the stream project.

3. The Organisms

Narrative relations of the actions of some individual organisms that stood apart from other of the study animals also acted as a guide for interpretation and analysis. For instance, commentary made about a feature noted about one individual organism was elaborated in narratives over several weeks and was ultimately seen (and related by the researcher) to be an influence on analytical decisions. In this case, a minor accident in the lab resulted in the injured individual becoming more notable than the others in captivity. The story of the injury was related several times to several people over an interval of many months and more attention paid to that individual organism than would otherwise have been the case. This constant re-telling of the story re-focused the researchers' attention on differences in the whole population of animals, the consequence of which was an analysis that might otherwise not have been considered.⁷⁶ Direction for analysis or data collection frequently came from individual organisms which are central figures in 'lab stories' where the re/actions of those individuals have provided the researcher new insights. It is from the actions of these central (organism) actors in these stories that decisions about analysis, data collection, and future research were based.

⁷⁶ During the ethnography I was in the position of observing the injury's occurrence, listened over several months as the story of the injury was related to others, and then listened to the researcher describe how the animals physiological reaction to the injury resulted in her thinking about the consequences of that injury for the whole population. She herself maintains that without having been there from the beginning (actually accidentally causing the injury) she might never have thought about the problem in that new light.

Stories are also a valuable resource about the organism being studied in the field. The experiences of others working with that (or similar) organisms or the observations of local residents can offer the researcher tremendous insights. For instance, narratives shared among local residents about where pilot whales and dolphins were traditionally seen dramatically reduced the time spent by researchers searching for them in at a field research site.

4. Solving Field Problems

Field researchers benefit from storytelling in several different ways, both in the field and back at the laboratory site out of which they run their projects. In the field, stories act as resources for potential methodologies to address one's own research-specific concerns. Through the stories related from person one to another situations that appear to be problematic in the field come to be framed as solvable problems. This is particularly significant, as resources available in other disciplines (i.e., journal articles, libraries) to help frame and solve research problems are often unavailable to those doing field ecology research. On ecology projects it is not unusual for several individuals to 'pass through' your field site in a season, and stories related in settings with those other researchers and (potential) volunteers provide considerable information to aid field research projects. The following field note provides an example of such an occurrence:

. . . a post-doctoral student, briefly spending time at a field station working on his own project, at lunch time overheard Sam (a doctoral student) discussing her plan to construct wooden enclosures to contain her study animals. The post-doc proceeded to relate a story about enclosures he had built in the past and the dimensions of those relative to his study organism, concluding with the comment that other people he knew had also used similar relative dimensions to contain animals successfully. Sam, who had been worrying about the adequacy of the

dimensions she had decided on, concluded that her design more than exceeded those dimensions and were therefore suitable.

Stories such as this one related both first-hand information and second-hand information and were quite common. An additional aspect of this type of methodological ‘lore of the discipline’ is that it would not normally be obtainable from books or journal articles even if they were available.

5. Membership

Membership in a community can be established in a number of ways. Unlike in particle physics, where one’s membership is established to a significant degree by one’s lineage (i.e., the research facility one worked in and supervisor one had (Traweek, 1988)) and the stories one tells, in the community of ecologists membership is established much more through what projects one works on than who one works with. In discussing how a graduate student should choose a research project, one tenured faculty member stated that “it’s much more important what you do with a project than where you work or who you work with.” Your participation in a project, and your subsequent acceptance as an ecologist into groups of ecologists, is then elaborated to others through the relation of stories. Relating stories of your work establishes what type of ecologist you are, what type of work you are capable of doing, and the language that others can use in conversation with you.

During my ethnographic fieldwork with ecologists, there were times that I joined new groups of graduate researchers who did not know me—and I noticed two patterns of interaction occurring repeatedly. In some instances I was excluded from the “conversational circle” in who was being addressed by the speaker when they were discussing various aspects of their research; I was an ‘outsider.’ When those present realized that my background in ecology research was significant—the complexity of what was being discussed increased considerably, more field-specific terms were utilized, and what was

being related became much more of a “story”—often of the heroic accomplishment type where overcoming adversity or observing a rare natural occurrence was described.

Realization of my background generally came about through two mechanisms. The first is related to “storytelling” as I responded to some commentary they were relating by comparing it to some field experience that I had—I told a story of my own. Varied social signals (eye contact, inclusion in commentary, asking of questions) suggested that this was a significant route into being accepted as a “member” of the group. The second mechanism which led to my being included as a “member” occurred through “vouching” by one of my key informants. In those circumstances, often in response to my informant sensing I was being excluded from the conversation, my informant told the members in the new group that “Mike has a graduate degree in biology from Guelph and has worked with....” In those situations a shift occurred in that I was now included in the conversation as a member, a position which increased as I participated in relating a story of my own to the other members.⁷⁷ Thus, “vouching” for somebody, including before they join the group, through telling stories of their field involvement also leads to membership and acceptance as an “ecologist”. It is also possible that the status of the person doing the vouching is important to acceptance in ways not yet determinable from the data.

6. Status

In addition to establishing membership, stories also contribute to ‘status’ within and across sub-communities—although not to the degree of hierarchies amongst physicists described by Traweek (1988). In high energy particle physics academic lineage plays a substantial role in how one is “ranked” as a graduate student or post-doctoral researcher

⁷⁷ This occurred several times before I realized what factors were contributing to my being included or excluded. It also warrants mentioning that these observations occurred numerous times in the months before I conducted the ethnography in the field and considerably before I began to consider the roles that stories played in constructing the community of ecologists.

and whether one is considered an “insider” member of the community. Amongst ecologists however, “status” can be established in a number of ways. Amongst graduate students such status seems unrelated to quality of work, however some social status accrues from the types of organism one works with and the stories that can be related about them. My field notes reflect several instances of this. In one case, a plant ecologist who works with an endangered flowering plant was labeled with a somewhat derogatory nickname based on the plant with which he worked. Although he reacted with good humor, there was also some irritation that the nickname “stuck,” because of its negative connotations. Another ecologist, who conducts genetic and field work with an extremely small invertebrate which lives on plants, expressed somewhat bitterly that he would “never get a date” based on the work he did, but that another graduate student in the department who worked with marine mammals was always “mobbed by women” even though “the rigor of his work is not all that good” (as related by the informant). The marine mammalogist constantly told stories about his work to people who I saw him with. Although from these stories it was difficult to clearly gauge the quality of his work, he received constant comments from people that he was doing “great work” which was “very interesting,” although his stories actually related few aspects of his actual research from which this could be gauged. Presentations he made at ecology conferences⁷⁸ were always quite well attended, although it was not possible to gauge the quality of his research from the conference abstracts. Observations of his informal discussions with people at these conferences reinforced that it was the organisms on which he conducted research and the narratives he related about them that played a role in his status as an ecologist. His work was clearly well regarded as a consequence of the research organism on which he worked, not because of the quality of his research. To provide some comparison, at a marine mammal symposium he was treated and attended to

⁷⁸ Conference presentations can be viewed as a narrative story constructed to persuade the conference attendees about the quality of one's work.

no differently than any other participant—in this setting his research organism had no particular mystique and his area of research did not command the attention it did in other forums such as general ecology conferences.⁷⁹

In some sub-communities of ecologists there is a more obvious “status” ranking between members than is found in others. A notable example of this is among herpetologists who gain status through both the size and variety of their “live animal collection”⁸⁰ as well as from the size of the animals they have in it and the “danger” element of the animals involved. For instance, more status accrues to a herpetologist for having a rattlesnake than for having a garter snake in his/her collection. Stories about one’s “collection,” as well as about the size of animals one has caught during fieldwork, clearly act as a vehicle for status. In a field project I worked for, the size (and number) of reptiles that had been caught was taken by many as an important indicator of your skills and abilities as a herpetologist and was a frequent topic of commentary. Field stories amongst herpetologists often concerned how “big” a newly caught snake (or lizard, etc.) was compared to those previously caught. Catching “the biggest species of X” in that group of researchers, or by oneself, was frequently mentioned to others over subsequent weeks, unless or until a “bigger one” is caught. Some status also comes from catching an organism which is uncommon or which had not been caught by others in the research group. For example, when working as a field assistant, I gained recognition by catching two individuals of a type of uncommon snake in a single day, even though I did so merely because I came across them in the course of looking for another much more common reptile. The story of my doing so was related several times by the other ecologist I was

⁷⁹ This type of ‘higher status’ is also given to graduate students who work with primates. In fact, ‘large’ and ‘smart’ often seem to predict the status awarded. This is ironic given that some of my informants suggested that it is far easier to address the same ecological questions with smaller, more frequently breeding, organisms.

⁸⁰ Maintaining a significant collection is, according to my informants, typical of herpetologists, especially male herpetologists.

with quite frequently (often with a tone of amused disbelief—mostly because she had authoritatively stated earlier that day that it was far too late in the season for those snakes to be found). Even months later she re-told that story occasionally as a “war story” about how she was “so wrong” one day. In this sense, particularly since the story is related when there are new members in a group I am with, it constitutes a “vouching” for my credibility as a group member.

7. Subject specific discourse

Appropriate use of subject-specific terminologies and discourse is also important for acceptance into the community of ecologists. Ethnographic observations in several settings suggests that not just any individual is accepted as a volunteer to participate in a particular project; the “key” for being invited to participate in a project seemed to reside in the stories one could tell about past projects in which one was involved and the language used to talk about them. For instance, using appropriate terminology to relate a story about crawling through marshes in the cold, early hours of the morning to assist in observations on birds was an effective “key” for being accepted as a participant in a project on reptiles.

Relating stories to other ecologists is important for indicating competency in and familiarity with field research practices, and other than helping establish “membership” may also contribute to finding new employment positions in the field. Familiarity with specific discourse and terms suggests that one at least has some competency with particular practices. Thus, listening to stories is also important. For instance, ecologists listening to a story about mist-netting may not be working with birds, but being able to mention mist-netting in a conversation about a project where there may be employment opportunities can provide the key-word that results in being “accepted” into a project,⁸¹ even if one’s actual

⁸¹ Knowing specific referents was invaluable in conducting this ethnographic work and was a distinct advantage of my former “nativeness” by providing me significant access to the community. For instance, at one point my field notes reflect that a professor I had just met “accepted” me after I indicated in the initial conversation that I knew that the acronym RFLP was the more specific term for micro-satellite work in

experience with mist-netting is minimal. The reverse can also hold true; lack of familiarity with terms can negatively affect the ability to obtain work. In one narrative a marine ecologist related not being hired to work on a field research project because he was unable to identify a particular group of organisms by name specifically (i.e., copepods), even though he was able to discuss the ecology of this group of organisms. The person hiring for the position considered being able to use the general terminology referring to the group as being quite important despite the individual's familiarity with other aspects of the project. A few weeks later, in casual conversation, copepods were the topic of several stories—if they had occurred earlier, the ecologist might have obtained the position.

The importance of using the appropriate term at the right time is well known amongst ecologists. An ecologist applying for a job was quite concerned that he be able to refer to the specific organism that a project was about by its scientific name in his application for a research position because he felt it would improve his chances of employment, even though he had considerable other research experience adequate for the employment.

8. Stories and “Newcomers”

For newcomers, being in settings where “war stories” about field experiences are exchanged offers several advantages related to their enculturation to ecology research practices, including appropriation of discourse (linguistic distinctions), domain specific concerns (i.e., the research questions that are asked), appropriate research and interpretive practices (field methods), and the importance of telling stories amongst ecologists. In this, stories contribute to their understanding in ways that the formal educational experiences may not (see Bowen, 1999 for an elaboration of this argument) since there is some evidence that traditional undergraduate educational experiences poorly prepare them to conduct fieldwork (e.g., Eisenhart, 1996). Our work with pre-service teachers with B.Sc.

genetics. Knowing the “inside” relation between those two terms opened a door for communication that resulted in his becoming a significant informant and participant in my research.

degrees suggests that they engage in few of the investigative or interpretative practices engaged in by science researchers (see Roth, McGinn, & Bowen, 1998; Bowen & Roth, 1998). Additionally, it is common lore amongst university science professors that most beginning graduate students are initially poor at canonical investigative and interpretive practices.⁸² A notable aspect of graphical/problem interpretations by undergraduate science students is the lack of stories which they use to elaborate their understandings of the inscriptions in contrast to those with field work experience who used a considerable number of stories, either from their own experience or as related to them by others, to help make sense of the same tasks (Bowen, Roth, & McGinn, in press; Roth & Bowen, 1999).

Listening to and participating in telling stories with old-timers was a notable component of the trajectory from being a newcomer to becoming an old-timer. Through this participation, and through assisting in field research, newcomers to fieldwork develop both the discourse and the storytelling modes of experienced field researchers. At first, newcomers are often quiet as discussions occur among old-timers. Occasionally, they contribute a short comment related to the conversation between old-timers and I frequently noted that these comments felt misplaced in relation to the rest of the discourse.⁸³ As time progressed, and especially as their field-related research experiences became "richer," these story contributions became more immediately related to the discussions between old-timers and were interjected at more opportune moments.⁸⁴ Thus, newcomers learned to tell stories as they appropriated the discursive strategies of old-timers. For instance, stories helped

⁸² I'm being quite polite here relative to how I've heard it expressed by various supervisors. "Hopeless" was a frequently used term. Eisenhart (1996) reported that the "Conservation Corporation" at which she worked considered the field skills of environmental biology graduates who came to it to be inadequate.

⁸³ I should add here that I never observed comments from one of these newcomers (whether an undergraduate or graduate student) being "rejected" in the discourse by those who were more experienced—either by professor, more experienced graduate students, or "amateurs".

⁸⁴ It is possible that the latter claim derives from more conversational room being left for the newcomers to contribute, but it is not possible to determine this from how the data was collected (many subtle social cues, including more frequent but short pauses at significant moments can contribute to this type of opening and changes over time are far too subtle to note from this type of investigation).

newcomers learn what subject-specific acronyms meant and when to use them. Ecology has a large number of domain specific acronyms, such as MSY (maximum sustainable yield), ESS (evolutionary stable strategy), and MESS (mixed evolutionary stable strategy), which can confound newcomers⁸⁵ when they are used in discussions of field experiences. This is even more likely to occur when locally contingent acronyms such as PBS (Pacific Biological Station) are utilized. It is through listening to stories, and waiting for those terms to be elaborated, that newcomers learn not only what the acronyms mean, but also when it is appropriate to use them to talk about various issues.

Another aspect of ecology unfolded to newcomers through stories is differences among types of ecology research that are often unclear to newcomers even after four years of undergraduate education. However, when newcomers hear even a few stories these differences can become quite clear. For instance, that some ecology research requires little field time and considerable time conducting analysis of samples in the lab, whereas other projects may require months of research in remote, dangerous locales but almost no 'follow-up' laboratory work is often made clear by the stories researchers relate. Such differences are important to consider when making decisions about graduate work or employment and the insights gleaned from the "war stories" of old-timers contribute significantly to those decisions.

Stories also develop a considerable sense of the relatedness of issues in ecology. Discussions of very disparate observations between old-timers, such as the example earlier about salmon and porpoise movement, develops awareness that very different projects can inform the analysis of each. For newcomers, stories also clearly relate that fieldwork is

⁸⁵ Earlier I pointed out that "newcomers" (to ecology) in our research group brought me fresh insight into the terrain of ecology. My having advance familiarity with terminology was also quite useful. I went to one ecology seminar with another member of our team who was not an ecologist. I later talked with her about how she experienced the seminar. It was apparent that essential aspects of the presentation, especially around domain specific terms, meant that she had not experienced the talk, and subsequently the implicit sociological functionings of it, in the same manner that I had. However, this is also not unlike the experiences of a newcomer to any discipline.

chaotic and that projects are emergent as they progress (unlike how projects are presented in formal ‘texts’). Newcomers unaware of this often find their first fieldwork to be a stressful experience. One ecologist told us that she knew of several people who dropped out of doing ecology research because of not being able to deal with constantly having to change plans to account for changing circumstances in the field, and observations on and interviews with MSc students who had conducted their first field season supports this. The stories this ecologist told to the newcomers with whom she worked implicitly related that flexibility was necessary to conduct field ecology research successfully. Finally, newcomers understand from stories that participating in conferences is an important aspect of becoming an academic ecologist. Discussions relating experiences at conferences (whether stories related second-hand, or about people whom they met, or stories about socializing and consuming alcohol (often a significant part of ecologists’ culture)) are commonplace and the (implicit) message that conferences and contact with other ecologists is important is clear.

9. Stories about ‘members’

“Amateurs” (as defined earlier) can be a considerable source of stories which inform the field practices of both old-timer and newcomer ecologists. Unlike many other science disciplines in which “amateurs” do not participate in the formal research settings ecology is a discipline that benefits substantially from the involvement of “amateurs”. Field researchers often use the stories told by amateurs (and newcomers) about their field experiences to evaluate their potential for participation in research activities. Relating stories that reflect success and perseverance in adverse conditions reflect well on the ‘teller’ and increase the likelihood of their being asked to participate in other projects. Stories about these amateurs and their competency in the field are also “passed around” amongst the field ecologists. Through relating these, field ecologists keep track of potential sources of volunteer field assistants they can use for field projects. In effect, this is a type of

“vouching” which lays the groundwork for those not present in a conversation to be included in a research project. However, this vouching can also be a negative reference to an amateurs competency at fieldwork and can serve as a warning about considering that person for inclusion in a research team (although negative commentary about a volunteer’s potential contribution to field research were infrequent; however most researchers who have used volunteers do have ‘horror stories’ to tell about their involvement in the research).

Stories about potential employers are also related between field researchers, both as praise for good employers and warning of bad employers. As an example, one particular employer on the northeast coast of Canada who uses ecologists as eco-tourist guides was mentioned by different ecologists three times in nine months. This was notable because the biologists all had different backgrounds, were located in central and western Canada, and discussed that employer without any prompting when they found out what my background in ecology research was. Two other ecologists, who had previously been aware of my background, also asked if “I’d heard what [this person] was doing now?” to find out if I was aware of his latest exploits. The field of ecology may not have “heroes” in the sense that physics does, but in the functioning of its’ research community there are “anti-heroes”—people (and their practices) who should be avoided.⁹⁶

Stories told at conferences also acted as a significant resource upon which ecologists drew to inform their field practices. During the field ethnography, informal narrative discussions with other ecologists at conferences were re-told as field research problems were being addressed. The statement from the lead researcher “When I was talking with X at the [recent] conference, s/he told me that when they were doing fieldwork they noticed that...” was commonplace when decisions were being made about how to resolve problems encountered in the field. Other members in the community would then relate stories of their

⁹⁶ This person was not the only person to be raised in discussion in this manner, but was the most frequent.

own experiences, which together constituted a pool of information guiding the final decisions made by the ecologist.

Discussion

Stories evidently serve important functions amongst ecologists, particularly since narrative exchanges among ecologists in informal settings communicate information not present in formal settings (particularly the non-conceptual aspects of the discipline; see Bowen (1999) for a complete discussion of this) or otherwise available when at a field research site. This is particularly true for newcomers who through stories learn appropriate discourse, domain specific terms and practices—thus stories help focus or ‘fix’ the lens of newcomers, affects their interpretive framework, so that they ‘see’ what an ‘old-timer’ sees—and stories contribute to that.

Similar findings have been made in other professions, such as medicine; “language employed by novices becomes an important source of information about their understanding of a case and the ability to make appropriate inferences” and adequacy of medical information is assessed on the perceived credibility of the source being a “good or bad historian” (Cicourel, 1990), which is related to their ability to describe narratively the medical history of a patient (Nelsen, 1997). In this sense, making a “case” or telling a story is equivalent to the impression management discussed by Goffman (1959), in which newcomers learn to tell stories which “fit” with those of old-timers and thus acquire membership as an old-timer. When individuals newly join a group, their “dramaturgical” performances as they tell stories are partly how their membership as an ecologist is judged.

Our ethnographic fieldwork emphasizes the importance of stories to field practices. When we were in the field, stories of what was done, who did it, what they found, and what was unusual/bizarre/interesting about their work occurred daily and comprised a large part of conversations even outside of the time fieldwork was being done (for example, while collectively doing laundry in town). Particularly in ‘leisure’ settings over coffee or

beer or when hiking after a conference, and much like the “shop talk” which is conducted while doing research work (Lynch, 1985) and the “war stories” in informal settings by repair technicians (Orr, 1990), narrative stories about field experiences are an integral component of communities of ecologists—apart from how they structure knowledge claims which are the consequence of research work. This happens in part because ecologists not only work with each other, but also frequently socialize with each other as well and, as a result of this, their socializing is tinged with tales of their fieldwork. As well, how and where their fieldwork is conducted, and how local residents can contribute to that, means that exchanging field stories is a necessary part of successful field research, particularly for newcomers, in ways which are unnecessary in other science disciplines—for instance, local residents are more likely to have noticed a rare pileated woodpecker than a quark or a particular chemical reaction so there is little need for a physicist or a chemist to survey local residents and talk about their work. Thus, realizing that the telling and re-telling of stories has important consequences for certain types of research has implications for the conduct of science education.

Implications for the Classroom

The structure of science classrooms in public schools is similar to that of field ecologists because they are often impoverished of written and experiential resources which can be called upon to support the conduct of “authentic” science activities (promulgated by current reform documents, such as NCTM (1989) and AAAS (1989, 1993)). Because of these parallels in the setting in which research is done, the roles stories play in ecology suggests that developing a culture of storytelling about practice would offer similar advantages to classroom efforts to engage students in science practices. This suggests that the interpretive practices of students, as well as their competency at conducting research in the first place, would benefit from exposure to other students’ narratives. However, this can only occur if students have the opportunity to engage in authentic scientific practices

which will allow them to develop a pool of stories to relate to others based on their own⁸⁷ investigations. Studies which have been specifically designed to develop story-telling about investigative work by students report advantages (see Roth, 1996b) for the conduct of their work similar to those found amongst ecologists.

Inquiry classrooms are difficult to construct when the teacher alone must do the doing scaffolding to increase the complexity of research conducted by the students and their understanding of it. However, when students have diverse experiences to draw upon, then stories of those experiences provide information for other students thereby reducing the teacher's responsibility to help each one individually with every problem encountered—this type of knowledge and experience is embedded in the stories told amongst ecologists. The heterogeneous groupings of experience and age encountered in functioning research communities of ecologists encourage storytelling and resemble the apprenticeship situations examined by Lave and Wenger (1991). The heterogeneous grouping is partly responsible for the enculturation of “newcomer” field researchers into ecological field practices and is a structure which would arguably improve science teaching in schools

Secondly, my observations (in schools and with ecologists) suggest that so-called “off-task” discussions among students occur because they do not have a variety of stories to relate to each other that pertain to their science classroom investigative tasks. To expect students not to converse is unreasonable. To expect them to converse only about their scientific interests when they have not accumulated a base of different stories through experience that they could relate to others is also unreasonable. When watching and participating with ecologists it is difficult to categorize their activities as being on-task or off-task from the perspective of their research work—they seem “engaged” in their work to

⁸⁷ There is not, after all, much to relate to others in stories when all students have engaged in identical class laboratory activities all of which were supposed to result in the same findings. Obviously, a range of experience within a classroom is needed.

the extent that they are partly because is it theirs allowing them to accumulate a series of narratives they can relate to others in their community. Allowing students in science classrooms to accumulate a pool of stories or narratives based on activities that they have participated in that others had not would result in more “on-task” discourse about science as students participated in developing their own communities of scientific practice and discussed those ‘unique’ experiences with others. Thus, apart from accumulating a pool of stories from their experiences, allowing students to work on diverse topics would also address critical issues of student engagement in their science education.

Science reform documents often call for developing a community of learners in our classrooms. Outside of schools, communities arise not only because of common concerns, practices and language, but also because of narratives about them that are exchanged among members of the community. If we really desire communities of learners in various domains to arise in our schools, then we must not only provide the formal structures for learning to exist, but also the social aspects of engagement which allow individuals to feel that they belong to a group with those common interests, practices and language because of the stories that can be told.

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Chapter 10:

The contributions of formal and informal settings
to the formation of ecologists

**The contributions of formal and informal settings
to the formation of ecologists**

Abstract

Ethnographic studies of scientists and science rarely focus on either (a) the enculturation of scientists-in-training, or (b) field scientists (particularly biologists and their “small science” work) but instead focus on experienced scientists who conduct research in laboratory environments. This is relevant to the learning of ecology for the locales where the formal learning about ecology occurs is unlike where ecology research is conducted—laboratory sciences, such as physics and chemistry, learn about the research practices of their discipline in settings similar to the environments in which such research is actually conducted. Drawing on three years of ethnographic work examining the enculturation of ecologists, this paper examines the formal and informal settings in which ecologists learn (about) their discipline and reports on the contributions that each setting makes to learning about the conduct of field research. Often ignored informal aspects of learning about the conduct of ecology research, such as story-telling in ‘leisure’ settings, are revealed as being important to becoming enculturated into ecological field research practices.

A bear could look back and see you. Padding across the log in a stream the bear might suddenly hear the whirr of the video camera, or smell your scent, stop walking, look up from its feet, and stare at you. And you know, as they probably know, that they can run through the tangled brush far, far faster than you can. You just hope that it doesn't occur to them to do so. [Reflective fieldnote after Ted's⁸⁸ discussion of his field research]

Research conducted in remote settings away from the formalized experimental settings found in universities is often a mix of science research and survival and is comprised of complexities which extend far beyond the actual conduct of the scientific research. For instance, when an ecologist does field research, she may realize that encounters with bears, during which they are within only a few meters of the researcher, may occur. This is important to understand field research, how it is conducted, and the knowledge claims that arise from that work. Yet, presentations about research work conducted in the field—particularly in the formal texts of lectures, textbooks, and journal articles used to enculturate newcomers to ecology—rarely detail the experiences of the field researchers in an explicit fashion; nor do they detail the methods used to collect the data in the study. This raises the question, “Where do beginning field ecologists (undergraduates or new graduate students) learn about the conduct of field research and how researchers feel during that work?”

Experience with field settings, either directly or as related by others, also affects perception of field settings. For instance, how a videotape of a bear walking in a forest is perceived depends on whether the viewer has ever seen a bear move through underbrush before. In the videotape segment about which the above field note was written, shown at an informal public talk, the video showed a bear moving slowly, seemingly with studied

⁸⁸ All names of our participants, other than those of the authors, have been replaced by pseudonyms. In some cases, details of the stories have been altered to help preserve informant anonymity, although the overall tone and function of the story has been maintained for analytic and presentation purposes.

deliberation, as it walked along the fallen, moss-covered trees in a British Columbian rainforest. Yet, how one “sees” that video depends on the understanding one has both of bears and of the setting in which the bear was seen. Before seeing a black bear when conducting ethnographic research with ecologists, we assumed a human could outrun a small black bear. However, after working as field assistants with ecologists in mountain underbrush, and after having observed bears moving through that underbrush, the videotape had different meaning—we now know that if the bear in that video had begun an attack against the researcher making the videotape, who was less than six meters away from the bear, then there was little the researcher could have been done to avoid that attack. Our framework for interpreting the video of the bear shifted as a result of his experiences in the field with bears.

Yet, it is clearly not possible for all field researchers to be able to experience all such possible encounters for a field sense⁸⁹ to develop which would allow successful field research to be conducted—the various settings from which one could learn about successfully conducting field research (either methodology or survival) must also play a significant role in communicating this information. For us, this raised the question, “By what means and where is critical information about field practices relayed in the community of ecologists?” From our research among ecologists, we present evidence that the formal settings of classrooms—lectures, journal articles, textbook writings—convey little of the information that is necessary for ecologists (especially undergraduate and graduate students learning to become ecologists) to effectively do field research and that other resources are critical to enable a future ecologist for doing this type of work.

This paper is about the appropriation of knowledge, *information*, in *formal* and *informal* settings by ecology students (i.e., individuals *in formation*). We address the

⁸⁹ We use the term “field sense” to describe the awareness of the context of the natural area in which an ecologist is working which allows him/her to conduct their research.

questions, “How are formal texts (both written and spoken) and informal texts (such as in bars, over coffee, and during informal public talks) in which ecologists discuss their work structured?” and “What are the implications of any similarities and differences for the enculturation of newcomers into the concerns, practices, and discourse(s) of ecology?” To address this we analyze texts from different settings including journal articles, transcripts of conference presentations and university lectures, informal public talks, discussions during informal meetings (involving both those who conducted the research and those who telling the stories second hand), newspaper articles and television interviews about that field research project, and narrated memories of graduate students who encountered bears in their own research. Examining these texts from several different settings helps us better understand how and where new researchers in ecology learn about the conduct of field research.

Our information was collected while we worked as field assistants with ecologists over two field seasons (during which we examined both their field research practices, their construction of scientific claims, and the enculturation of newcomers into these practices); conducted over two dozen semi-structured interviews (with both ecologists and non-ecologists) during which they interpreted (their own and other) scientific inscriptions; observed and recorded presentations at conferences, symposia, and departmental gatherings; socialized after working hours with groups of under/graduate students, post-doctoral researchers, and university professors; and conducted a video-based interpretive study over four months in a second-year university ecology class. In addition, our analysis is informed by our past work with students with and without BSc degrees as they interpreted inscriptions and conducted field research projects of their own (see Bowen, Roth, & McGinn, in press; Roth & Bowen, 1999) and on our work with grade eight students as they conducted ecology field research (see Roth, 1996; Roth & Bowen, 1993, 1994, 1995).

Previous research on enculturation into science practices

Few ethnographic studies exist that examine the enculturation of new researchers into the practices of scientific research. A study of the formal texts in undergraduate physics detailed how students engaged in group problem solving activities working on theoretical and abstract problems. During these activities, students develop an identity as part of a “physics actors network” within which they learned to explain physical phenomena primarily in mathematical terms (Nespor, 1994). The textbooks are “useful in holding networks together in a stable configuration and keeping activity ‘on-track’” (p. 59) so that students become enculturated to the standardized practices and interpretations of solving the mathematical problems. These mathematical problems are presented as if they were physics, not as mere representations of phenomena (which mathematics approximates). In addition, the lectures students attend differ little from the textbooks. Overall, the descriptions of the programs suggest that undergraduate physics students learn little about doing physics research but learn to use mathematical formulae. Even at the graduate student level, formal physics texts differ little from those of the undergraduate physics students (Traweek, 1988). Both graduate and undergraduate students study the heroes of the discipline and learn how to succeed by examining how those heroes were successful. Graduate students learn a little about the style of “doing” physics by listening to stories of success and failure. Both undergraduate and graduate physics students are enculturated into thinking of physicists (and then themselves, if successful) as people who are specially gifted and above the common milieu.

An examination of an undergraduate program in environmental biology (EB) led to the conclusion that the “EB view of a scientist is a kind of challenge to the hegemony of the theoretical, laboratory, or research scientist who is widely celebrated in the physical sciences” (Eisenhart, 1996, p. 175). Employers of graduates from this program are dissatisfied with their preparation to deal with “real-world issues” (p. 180). However,

students appear to be well schooled in the concerns of environmental biology, but not skilled in balancing the concerns of different communities (i.e., business, political, etc.) or in applying them at their future job site.

Research on enculturation therefore suggests that undergraduate science students are enculturated into the concerns, practices, and claims of their respective disciplines but little into the respective research practices. An important aspect of scientific research is the construction and interpretation of inscriptions (Latour, 1993)—particularly tables and graphs—which are central to the claims derived from research.

Science Graduates do not Enact Canonical Scientific Practices

Competencies with graph interpretation and field research

An understanding of what science practice competencies accrue to students during their undergraduate study provides a foundation to discuss the importance of understanding from where competencies at field research arise for ecologists. Our work with graduates of various undergraduate science programs provides insight into the development of competency with inscription use and the conduct of field research projects. We summarize the inscription practices of these students (Roth & Bowen, 1999; Bowen & Roth, 1998) and then sketch the competencies of these individuals as they pertain to conducting small field research projects.

When asked to interpret a graph individuals with science degrees frequently have difficulty in elaborating an interpretation; these difficulties also exist when they work in groups. Interpretations are often referentially isolated and the individuals get stuck within the details of the signs themselves and do not draw on their knowledge of the world to help them read the graphs. This often results in breakdown of the interpretive process; individuals and groups are unable to proceed in their interpretations of some graph. For example, these students used only a small number of resources, such as references to natural populations or mathematical tools in their interpretations of a population graph. In

addition, the linguistic resources brought to the graph interpretation task made it difficult for them to make important distinctions between terminologies necessary to develop any interpretation appropriate to the academic field. The resultant ambiguities made arriving at a shared interpretation during group work difficult. In general, students learn to provide correct answers to specific graph-related questions but do not come to make linguistic distinctions, increase their knowledge of specific populations, and do not develop general interpretive skills (Bowen, Roth, & McGinn, in press). Rather, students learn to apply the professors interpretation of specific graphs.

Science graduates do not enact canonical research practices or interpretation of data sets. For example, students in a post-baccalaureate program conducted a small field research project in ecology for which they were asked to examine (cor)relations between one biotic feature (such as density of a type of plant) and two abiotic features (such as soil moisture and temperature). They conducted the study in groups of two or three and then wrote group reports on their findings. Although their reports contained most of the components of scientific reports⁹⁰, there were problems with most regarding the content of each component. Generally, students wrote research questions unanswerable by the study design, inappropriately operationalized the constructs to be used, inappropriately reported and transformed data, and failed to match research claims and research questions or data.

In total, there were 12 reports containing 24 research questions. In many cases the investigations were framed as causal investigations ($N = 14$) which were not possible to conduct given the parameters of the project. In seven reports, variables were inappropriately operationalized, replication was problematic or sampling was done ineffectively. The subsequent reports reflected some of their difficulty with the conduct of the field research. Tables ($N = 14$) were used to summarize data but several were structured

⁹⁰ An epistemological Vee reporting diagram was given to them as an example and this provided prompts for the various standard sections of scientific reports and for the typical inscriptions used by them. Thus, the inclusion of these is unsurprising.

in non-standard ways and did not aid in understanding any patterns. Ten reports used graphical inscriptions but in such a way that these negatively affected interpretation of the data. They used inappropriate graphs when another type might have better portrayed the relationship (e.g., line graph instead of a bar graph or vice versa), infrequently fitted lines-of-best-fit, and conducted no outlier analysis. In addition, there were often structural problems which confounded interpretation. With this work (for details see Bowen and Roth, 1999) we gained insight into students' difficulties of interpreting inscriptions. Their experience with graphs was such that they could not use them to understand their own experiences; it was perhaps unreasonable to expect them to be able to re-construct the experiences of others when interpreting inscriptions.

It is possible that these science program graduates are unrepresentative of those who go on to actually do field research, however this is not supported by our observations in the community. For instance, it is common lore amongst biology professors that even those graduate students who were top undergraduate students initially have few competencies at conducting field ecology or laboratory research. As was clear from our informants, a notable consequence of this for those who engage in field research, most particularly those who engage in field research during which one is working alone, is that little useful data is collected in the first field season.

Students' interpretations of graphs contrasts those of experienced field researchers reading graphs related to their work. Experienced researchers engage in a dialectic process that draws on (i) their own research experiences, (ii) commonly-held ecological knowledge touchstones, (iii) examples of live populations, and (iv) anecdotal⁹¹ narratives related to them by others. Frequently, we observed a combination of these resources. For example, Jan (a post-doctoral theoretical ecologist) drew together three of these features as he made

⁹¹ This is an "emic" term used by our informants to distinguish formal scientific claims (such as found in journal papers) from field observations which they (or others) had made but which were not yet substantiated by a solid evidentiary foundation.

sense of a graph depicting a population of organisms with density dependent features affecting the population birth rate but not death rate.

This is an extreme, when you start to go from the traditional density dependent factor affecting declining birth rate to one that takes us all the way down below here <below the death rate line> [this] is a fairly extreme Allee effect. You could just argue that this doesn't happen. It's what this is. That's the Allee effect. Trouble finding mates when they're at a very low density. Like [ecology professor] was telling me a story the other day. He said they're at the low of the snowshoe hare cycle in Killarney or something, no hares around at all for miles and, he caught one female hare and it's pregnant. There haven't been any hares for three years in this area or something, he said. He's very skeptical to <how> this happened.

When scientists develop interpretations of graphs, they use a combination of resources; as a result, they make sense of individual graph components and the relations between variables depicted. Stories, such as the rabbit story above, accumulated in a variety of settings frequently play an important role in the interpretations of experienced researchers.

Given that graduates from baccalaureate science programs experience such difficulties when it comes to field research and graph interpretations, we have to ask "How and at what point do scientists learn to do research and interpret graphs?" Since the common experience shared by undergraduate students and beginning graduate students in biology are the formal texts of science—lectures, textbooks, laboratory activities, and journal articles—an examination of those should help us understand the competencies of beginning ecology researchers.

Formal Settings: Current Biology Education Settings

The formal information sources available to undergraduates present knowledge about ecology in an impersonal style with infrequent reference to the scientific practices and field experiences of the scientific authors; reports thereby constitute "a world from which

persons are virtually excluded” (Gross, 1996, p. 70). This information is rarely presented against the background of the social contexts in which researchers work, a context which is critical to understanding the different perspectives and interpretive stances that ground the claims. The formal texts of undergraduate education rarely include reference to the field research and methods. When researchers *in formation* engage in their first projects, they therefore have a limited stock of resources on which to draw for judging the quality of their work. This is especially problematic in any science conducted in the field rather than the laboratory including ecology, archaeology, and geology. Newcomers to laboratory sciences such as chemistry, physics, or genetics find themselves in settings rich in informational resources—post-doctoral students, doctoral students, and professors work in the same locale as the new researchers and academic paper resources are readily available. However, field research is often conducted in far-flung settings far removed from other individuals and formal academic resources. In some settings, such as field stations, this is less problematic as there are often others who can provide help (see Nutch, 1996); in many other settings there is substantial isolation⁹² and little academic or technical support. Thus, researchers *in formation* often experience considerable frustration when they start their research careers. It is latest at this point that the problematic of formal education become salient to the newcomers.

In this section, we provide an analysis of information sources encountered by students during their formal education. During their time at the university, under/graduate students obtain access to *information* about science from four basic, *formal* sources: lectures, textbooks, journal articles, and formal verbal presentations (at conferences, symposia, etc.). In the following sections we describe these settings and what informational resources for a new field researcher (*in formation*) are present in each.

⁹² This claim is based on informants relating, for example, being by themselves living in a tent on a remote island for two months at a time, in a tent trailer in a remote wilderness area for three months, or hiking in the jungles of Borneo for eight weeks at a time to find and observe their research organisms.

Textbooks and Formal Courses

Textbooks and lectures are highly similar in that they present a purely factual view of ecology, a view from which human agency has largely been eliminated (Bowen & Roth, 1998; Nespor, 1994; Roth, Bowen, & McGinn, in press). Both of these *information* sources provide those *in formation* with a limited sense of ecology. The *information* presented is in the form of broad conceptual knowledge claims that constitute compilations of individual research projects. The *information* is presented as if there was complete agreement amongst scientists within the discipline as to the interpretation of the data; the sources from which the *information* was culled are rarely discussed. Pieces of *information* are matters of fact as if they existed independently of their own constitutive historical foundations. This ahistorical nature also extends to the variables presented conferring to them an a priori nature independent of the knowing subject.

This ahistorical way of teaching ecology was also present in practical activities for undergraduate ecology students. Our observations of a field research exercise suggests that students experience these activities as disconnected and the research methods as inviolable, pre-determined, and standardized. The following field note provides a sense of the experience of participating in such activities.

The first groups are sent out to set up in their transect. The TA gives instructions and descriptions of how beach transects are done while the rest of us are still marooned on the edge of the parking lot. We are to lay out transect lines every 50 or 100 meters which s 'predetermined in the lab before going out using Canadian Hydrogeographic Survey maps and then checked in the field' using differential GPS. She describes to us how we are to measure 1-metre quadrates every few meters down the transect line; we are to measure the distance from the center of each to the transect line but we do not have a description why the quadrates should be at different distances from the line other than that the sites chosen were to be

random. She tells us that we should record the substrate, time, and location (latitude and longitude) on the sheets she had handed to us and that we could “never have too much information.” She continues to tell us that this was an intertidal survey but that normally a subtidal survey to fifty or sixty feet under water would be done with a diver. She tells us to head down to the midtidal area, to pick a random area, and to measure the distance to the line. We proceed and stop at an area that was sort of clear. The TA brings us a plastic frame. We are to use mining tape to mark the corners and then pass it on. By eye-balling, we turn the quadrat into 9 equal areas. I stand beside Nancy and was responsible for section C3. Nancy, holding the clipboard, discussed with others what should be looked at.

The students in this field note conducted a cookbook exercise for which they attempted to follow step-by-step instructions. Each group only participated in a part of what constitutes a whole research activity. They collected their samples from one spot along the transect line and only later, after sharing of data amongst groups, wrote their reports in which they examined the data for patterns. The students who participated in this activity experienced ecological field methods as standardized procedures provided by an external authority who had made all relevant decisions beforehand. Outdoor research exercises such as this one are treated by instructors as activities that are separate from both the lecture material and the exercises in the laboratory. This made it difficult for students to identify the organisms because they had not previously done any identifications. They not only had to learn new field methods but also the organisms by relying on field identification sheets that they had not seen before; this identification is in itself a difficult task (Law & Lynch, 1990). The students recorded numerous mistakes in identification—not surprising given the paucity of resources on which they could rely. Even when they realized that errors in counts had occurred corrections in the total recorded on the table were not made. The students’ goal was to have the data sheet completed to the satisfaction of the TA so they

could later write a laboratory report based on the data—their orientation to the task was notably as students, not as researchers with a vested interest in defensible data recording. Clearly, the point of the exercise was that student understanding of the distribution of organisms was to develop from the analysis of the entire classes' data set, not that this analysis and which variables one should attend to should emerge from observations arising in the field. The physical discomfort often experienced by field researchers as they conduct their work was the one aspect of field research students could in fact experience. However, this 'real' aspect of field research was rather underappreciated by the students who attributed the discomfort to poor planning on the part of the instructors.

Journal Articles

University students at the senior undergraduate and graduate levels also experience *formal* contexts as they read journal articles and attend conferences and symposia. Unlike textbooks and lectures, which portray the knowledge foundations of ecology in broad strokes, these resources focus on reports of individual research projects and how they contribute to the overall understanding of ecology. Many authors (e.g., Gross, 1996) note that the *formal* writings of scientists dramatically underdetermine the activities in which they engage. They thereby portray a depersonalized image of ecology which re-affirms the objectivity of their work. Here, we conduct an analysis of parts of the 'Methods' sections of two journal articles written by an author to whose informal accounts about his research we later return. In the course of his work on a particular fish, he had made observations on bears and their feeding on salmon. We determine what cues these articles offer to researchers *in formation* to *inform* current or future field work. We later contrast this *information* in formal contexts with that provided in *informal* settings such as presentations to lay audiences or with graduate students in a bar ('B(e)ar Stories').

The first journal article (in a major journal in the discipline) presents aspects of bear genetics and its implications for discrete populations and population distribution. For the

present analysis we focus on the part of the methods section dealing with how the “Samples” were obtained:

DNA from [the bears] was obtained primarily from muscle tissue, although blood samples were used from [X] members from [site]. A hide preserved with salt was also used because fresh tissue was unavailable. Sample details are given in Table [X].

This text describes the body part from which the tissue samples were obtained. A table lists fifteen geographic locations as sources of the samples, how many samples were collected at each site, and who provided the samples (mostly the authors themselves). Thus, sampling was discussed in two forms: location of the tissue samples on and source location of each bear. From the information in the table, a reader might also infer muscle tissue as the preferential tissue for conducting the DNA sequencing technique used and the geographic range and an adequate sample sizes for such a study. The remainder of the ‘methods’ section provides considerable detail of the genetic sequencing activity, although a graduate student interested in conducting such research would find few resources detailing how such samples are actually collected from a bear.

The second journal article makes reference to the first paper and deals with patterns in foraging behavior of bears. It offers considerable detail about doing the research (Table 1). The variables being examined by the researchers were presented as if they were predetermined before the fieldwork was conducted. A matter-of-fact neutral tone, typical in science writings (Gross, 1996), is used throughout when describing the actions of the researcher, even when describing situations such as following a bear at a distance of 2 m. In keeping with our findings of inscription use in ecology journals (Roth, Bowen, & McGinn, in press) these articles provided detailed captions and explicit readings of the inscriptions so that the readers were channeled into the interpretation of the graphs desired by the writer. So, these articles are structured so that the claims appear unassailable,

however they offer few resources to new researchers desiring to conduct such research themselves.

Table 1: Summary of methods section from paper dealing with bear foraging behaviour.

- geographic location of investigation
- number of [salmon] returning and approximate dates of return
- date of movement of [salmon] from estuary to stream
- period observation conducted in, over two different calendar years
- number of times (with approximated times) observations (“visual surveys”) of [bears] were made in daylight
- number of times (with approximated times) observations of [bears] were made at night–time (and equipment used)
- local sunrise and sunset times with approximate length of dawn/dusk at that locale were described
- geographic location relative to the [bears] for observations in estuary and distance of observation (“5m to 100m”)
- one sentence description of how researcher moved (I moved quietly to increase the likelihood of my seeing a bear.....).
- researcher response to encountering bear described (“I followed them and recorded their activities (2 m to 25 m distance).....”)
- number of times each day (with approximated times) “complete surveys” of the stream were done
- one daily search for fresh uneaten carcass remnants abandoned by bears in the riparian zone

Formal Verbal Presentations

We observed and recorded two formal presentations about this research with bears, one presented by the principal researcher and one by a graduate student, at two different symposia 16 months apart. (To be considered “formal presentations” they met the following criteria: a list of speakers with presentation times was printed and distributed to

the attendees, there was a common theme to the series of talks being given (e.g., “Nth Annual Vertebrate Symposium”), presentations had a “chair” who introduced and closed each session, presentations conformed to a standardized format (i.e., 15 minutes with slides/overheads, questions from audience) and reported on research. As is typical for ecology, the presentations often involved preliminary results of research which is still active. The two presentations we discuss here were typical of those we saw at over eight such gatherings we attended.) Both presentations were similar in structure providing an initial background to the research by showing color images with a commentary about what was being seen. These included images of the watershed, a map, the salmon species, the bears, a carcass being consumed/left behind by a bear, and so on. The images of the research site and organisms were followed with a presentation of various inscriptions used to represent the findings. Often, as with journal articles, detailed readings of the inscriptions with accompanying hand gestures to emphasize the important components were provided. In addition, graphs and tables were presented in clusters in support of the claims presented.

The text of these talks dealt, in the majority, with constructing a persuasive rhetorical argument so that the knowledge claims at the end appeared unassailable. This included the amount of time spent doing the study, the variables chosen for examination and the rationale for their being chosen (from which methodology could sometimes be inferred), the amount of data collected, and the juxtaposition of text and gestures that accompanied the inscriptions. Physical objects (and organisms) constituted privileged *information* and the human agency during data collecting was down-played. The following segment of a presentation by the professor illustrates these points:

<Describing an image> The bear here captured a salmon and is bending over and is just sniffing to see what sex the salmon is and then continued into the forest where it is consuming it, normally about 50% of each carcass. So this is what I spent my

time watching. After the bear departed I would go and then see what tissues the bear did not consume, look at the sex of the fish, I would look to see if it was gravid when it was captured and that's how I started to collect this data. The bears spent quite a bit of time after capturing the salmon and going into the forest and with it came usually about a hundred and fifty crows and often up to two hundred gulls following the bears around.

This description contains *information* about bear activity and the data collected, but there is little from which a researcher *in formation* could gather about how that data was obtained. The ordering of the *information*, undoubtedly done for rhetorical purposes, presupposes *information* obtained by doing the study in two ways. For instance, the statement that the bear consumes 50% of each carcass requires that the initial fish weight—*before* the bear consumed it—was either known or determined, and for a new researcher how this was determined in this study is important information. Additionally, that *information* is described prior to the study itself, even though it was determined by doing the study. Generally, formal presentations focused on where the research was conducted, what organism(s) the research was conducted on, and what findings were made. Little information was available about the methodology so that these *formal* presentations bore a strong resemblance to textbooks and lectures. In essence, *formal* talks present *information* such that those *in formation* can gather little about the process of research.

Experiences of New Researchers

What are the consequences for new researchers of the enculturation to ecology and field research in the manner described above? It is not surprising that our graduate student *informants* complained about the lack of access to *information* which leads to undeveloped and underdeveloped understandings regarding the contingencies that mediate field research. One of our *informants* (a doctoral student) suggested that the main reason for quitting

graduate work were the unpredictable factors that impeded with the research. Researchers *in formation* often experience such difficulties as unique to their situation and attribute the blame to themselves because the *formal* sources never presented such problems.

I was surprised by the bad luck I had in the sense that I thought if I really. . . up to this point in my university career if I worked really hard it would show, you know? . . . And I tried really hard last summer but it didn't matter. I had crappy luck. I didn't get to sites. My protocol was ill-suited for my species. My supervisor over in biology says that ya, we probably should have changed things around. She just wasn't aware of certain aspects of my species, blah blah blah. So yeah, there were things I couldn't anticipate. Things I had no control over. And uh, so that part was hard to take. [Carole, in interview after her first field season]

In addition, researchers *in formation* rarely know about the isolation and independence which are also features of field work. Graduate students who had acquired their first field experiences in the past season discussed their isolation in the field, the effect it had on their work, and how they wished to a different supervisor.

I'm not really comfortable striking out on my own. And that's kind of what I was expected to do in the field last summer. Which in a sense is good for me because I'm not good at that but it, it forced me to do that. To some extent that was probably helpful but it also makes me feel that the data I collected is seriously flawed. I know it is. In large part due to mistakes that I made. [Carole]

This isolation and the lack of input regarding field research methods meant that new researchers were insecure about the quality of their work. These concerns about the quality of data, and the lack of any reference to compare their work to which would allow them to receive affirmation for the quality of work, was a frequent stress factor for researchers *in formation*.

Researchers *in formation* often recognize in hindsight that their undergraduate experiences poorly reflected their newly gained experiences conducting research. Carole had completed one field season and considered dropping out. Her reflections are indicative of her discontent with the realities of conducting field research:

They really didn't spend a whole lot of time in my undergraduate program talking about what happens in real science. You know, it's like, you get these very pat results and, textbooks are marvels of this right? They package everything up as if it's all very neat and tidy and this is what we've figured out up 'til now and it's all packaged as if there was no problem getting to that stage. It was all a very nice linear progression of great minds and adding a little bit to the pile and standing on the shoulders of giants and all that crap and then, you know, you don't hear about the real things that don't make sense. And the things that don't fit and the problems that you have. There isn't much emphasis put on that. You might have the odd professor that'll give you the odd anecdote about their research, but, very little, very little, about the realities. [Carole]

The contrast between science as practiced and that portrayed in her undergraduate lectures caused Carole considerable stress. She wanted to conduct field research that was similar to the science with which she was familiar from her undergraduate education. The uncertainties of field research—what should be measured, what variables are important, the dealing with missing data caused by bad weather—she found hard to cope with. Further, her research meant spending weeks in the field collecting samples in remote areas so she had no peers to rely on, no email to use to ask questions of her supervisor, no feedback on whether the decisions she was making about research were the right decisions—she considered field methodologies as subject to externally determined criteria of 'correct' or 'incorrect'. Left to her own, she struggled with every situation "guessing this or that was the right thing to do." Carole considered learning to do research as a process of trial and

error and was discontent with “not knowing if a decision was right.” She felt that her methods would be judged external to her data, her arguments, and the context in which they were applied. If she had known what field research was like, she would have never started a graduate degree in ecology.

Clearly, the *formal* structures of undergraduate and graduate education in ecology poorly prepares students to do field research. This raises the question, if field research and field methods are communicated so little in the formal settings of ecology, how do new researchers develop competence and confidence in conducting field research? Here, *information* exchange between researchers in *informal* settings appear to provide substantially more to researchers *in formation* than the *formal* settings. The paucity of stories of field experiences in the formal texts of ecology, the important role they play in interpretations of conceptual claims, and their potential role in relating field research experiences suggests an analysis of informal settings in which ecologists gather may offer some insights.

Informal Settings: What Graduate Students Learn

During our two-year ethnography we spent considerable time interacting with and observing ecologists in *informal* settings. These settings included coffee shops, pool halls, bars⁹³; cars (as we travelled to conferences or field research sites), *informal* events at *formal* conferences, and private homes of a participant. *Formal* sessions (such as symposia) were frequently followed by attendees adjourning to a local pub for *informal* meetings. Finally, we considered presentations to public groups as informal settings.

⁹³ Field scientists appear to enjoy bars. Our informants in ecology, geology, and archaeology all relate numerous stories of drinking and intoxication which is part of both their field work and the “legends” of their professional practices. Stories exchanged included relating how some graduate students (as well as professors) were “known for” how much they drank at social gatherings. This often was even considered part of attending conferences, for instance our informants related stories about “the socials” at conferences at which alcohol was freely provided. Our field notes relate many such situations and stories. Participating in this community as an ethnographer often included participating in these practices.

Our observations in the *informal* settings suggest that different types of interactions occur at different times and places. This is often related to the amount of research experience the ecologists have. Thus, there are more conversations about field research in groups which included field researchers with PhDs in their composition than in groups composed of just MSc students. In the presence of doctoral students but absence of PhD researchers, fewer stories about field experiences are exchanged. In groups composed of MSc students only, field work stories are even less frequent. It is notable that in conversations about research work new MSc students (even those who had participated in numerous research projects as field assistants) often do not participate in conversations about field work. As time passes, even without having gained new field experiences, these students begin to participate to an increasing degree up to the “old-timer” level.

When someone joins a group of ecologists who know each other it frequently leads to conversations about field experiences if the joining person has a science background. The conversation takes notably different turns if the joining person is perceived as a non-science person. We recorded numerous instances where the conversations became more technical and work-oriented after those present were told that we, the authors, also had graduate degrees in science. However, the case of non-science people joining a group of ecologists resulted in a change of the conversation.

Unlike the work of laboratory-based scientists, ecological field research varies widely in terms of its geographic locations and circumstances. Even ecology researchers from a single research group can work in geographic locales distributed around the world. This lack of similarity in research settings provides ecologists researchers with variability in their personal experiences. Thus, when groups of ecologists congregate they possess considerable experiential resources in their conversations with other ecologists permitting members to find common aspects in their observations, practices, and conclusions.

The stories we heard were of several different types and served different purposes; they differed markedly both in form and content from the formal exchanges discussed earlier. Substantial *information* about the research work in field settings was exchanged in exactly these situations and noted by its difference. We noted four general types of stories that deal with the conceptual or experiential nature of ecology research: (a) stories about ecology based on the tellers personal experiences (b) stories about ecology that were being re-told (after being initially told by somebody else in a previous setting), © stories of the field which are used to reflect typical situations in ecology and (d) stories of the (hero and eccentric) characters of the field and their activities. These narratives served different roles, including information about surviving and conducting research in field settings (often related as allegories from which a listener could infer what to do or not do in their own research), how to interpret different observations, and in many cases provided a foundation for social cohesion of the community.

Informal conversations constitute the main source of *information* on field research practices for researchers *in formation*. Such *information* takes a narrative form. We illustrate the use of these stories through presenting a series of field notes and anecdotes collected from *informal* settings over an eighteen-month span. To maintain an interpretive thread with our earlier content analysis of conference presentations and journal articles, many of these stories are about bears—in part because, more than any other organism, bears formed a common thread in discussions amongst ecologists across research settings, topics, interests, and locales through this community. This focus on bears was particularly notable because only three researchers in the communities of ecologists we worked with actually did research with bears (and one of these never participated in any of the informal gatherings that constitute our database).

Storytelling, such as engaged in by ecologists in informal settings, does not often appear to be done just for reasons of entertainment. Usually embedded within the story

being related is an allegory about what actions are appropriate or inappropriate (depending on the narrative) when conducting field research. These allegories can deal with issues of safety, what to be careful about from a research perspective when doing specific field work (such as collecting lizards), cautions about using volunteers, and warnings about working with specific individuals.

Safety Allegories

Ecological fieldwork can be fraught with danger. Poisonous snakes, cougars, and bears are but a few of the dangerous wildlife a researcher may encounter, but numerous other hazards also await the unwary researcher. Although these hazards warrant little mention in the formal texts of the discipline, stories about safety issues are frequently exchanged amongst researchers in informal settings—particularly those working in similar geographic settings. Ecologists, either ecologists *in formation* or those from other geographic areas, rely considerably on *information* contained in the stories to develop their local knowledge about any hazards in the area. Allegorical stories were quite frequent in *informal* settings and provide *information* which pertains to doing effective research.

July 4: While driving to the research area Stephanie [an undergraduate field assistant] and Sam [a doctoral researcher] are talking about Cary (another doctoral researcher who has just left the field site who Stephanie was first working with) saying that he was paranoid about cougars and bears, and was always worried that there would be cougars waiting on the roof of the trailers for somebody to come out. Stephanie said that it was like he was almost going to buy shotguns for his field research team to carry for safety. Bear safety was discussed a bit and when we hopped out of the car, and start putting on our packs, water bottles, etc. Stephanie demonstrated a trick she had been shown—how to “make yourself big” by pulling your sweater up over your head and onto upraised arms so that the bear would be scared off. [field notes while doing field research]

The example is an allegory that deals with field safety. In groups such as this the hierarchy within the research project does not dictate who contributes to the conversation. Here, the extent of the local knowledge seems to be a better predictor. *Information* is shared among participants. A notable aspect of this exchange is that field lore such as “how to make yourself big” is not necessarily based on experience but on other *information* sometimes derived from exchanges with other field researchers. Topics such as this are not discussed in *formal* situations. The de-personalized nature of the formal texts would not lead a researcher *in formation* to suspect that working within a few meters of bears really presented any danger. Field researchers who have had interactions with bears relate their stories in *informal* settings about these encounters with much greater intensity than that expressed by Stephanie:

July 15: In one informal setting, a field worker related (to others not involved in the project) how when rushing back from a field site one day without a second thought he hiked along a trail at the edge of a marsh which ran towards a pond of water. The next day, sitting on a ridge overlooking that trail, he saw a mother black bear and a cub tumbling along the trail towards the waterhole. He said that he “knew” that such a trail was probably one used by wildlife from what he had read before, but now he **knew** [his emphasis] that wildlife had made it, and really used it. He swore he’d never use a trail like that again, and I (and the rest) filed the story away drawing the same conclusion.

Safety allegories were also present in stories relating the conduct of field research. The following field note relates a story told as a warning to field assistants to encourage them to pay attention to the surroundings while gathering data. This story was for the benefit of a less-experienced researcher and included the warning that one should (i) listen for twigs breaking and (ii) leave rather than risk a confrontation.

July 21: Later in the afternoon, just after 5, Sam went to a site up the road she hasn't visited with us before. Over dinner she said it was unnerving because while she was flipping rocks she could hear sticks breaking but couldn't figure out why. She then noticed that a bear was in her site eating berries. She watched it a bit, figuring she'd see if it left, but it was showing no signs of slowing down on its meal, so Sam left rather than risk a confrontation. [GMB field notes]

These tales of shared common experiences of survival also contribute to the social cohesion of the community of ecologists because they are examples of common experiences individuals working on even quite diverse projects can share. In an exchange between two MSc students near the end of their program the dangers of participating in field ecology research and the precautions that should be taken come to the fore:

RR said no, [she didn't miss doing field work] because last year had been hell, and that [turning to another researcher present] he mustn't be missing it either, because his field season last year was pretty rough too. Nat said he was missing it, but figured if he was out this year then he'd be visiting the hospital even more this year than last and that he thought he was just too old to hack field work any more. He talked about his injuries, how he'd gone to hospital numerous times, and then RR related her hospital trip.... 'I slipped off a log when marking a trail with orange tape and fell onto my ribs across another log and fought for consciousness and then passed out. I awoke 15 minutes later with my face buried in the moss, draped over a log [she described this very dramatically] almost unable to breathe or move. I painfully made my way out of the woods, which thankfully I was only into 100m, to my truck and then drove to my camp. It took my [camp] partner three hours to drive me to the hospital over the logging roads with every bump causing me to stop breathing because of the pain and they kept me off work for ten days.' After she concluded her story, Nat asked if she had spikes [on her boots], to which she

replied no. He berated her for that and for not having other safety equipment with her so that after she had passed out she'd be able to call for help if she couldn't make it to the road on her own. [GMB field notes]

Safety issues were ever-present in stories related about field experiences, especially when newer researchers were present. To newcomers, stories like this relate the physical rigors involved in doing field research serving as a warning for what they might expect. However, these stories seemed to be related less for the utilitarian purpose of exchanging information and more for the sharing of common experiences which contributes to the social cohesion between the ecologists.

Methodological Allegories

Other stories were told which quite clearly were meant to provide insights into field research methodology—as a warning against or a suggestion for what actions may be appropriate for certain research activities in the field. Given that most formal texts contain few resources about the conduct of field work on which new researcher could draw, allegorical stories which deal field research practices have particular significance to the enculturation of newcomers into the practices of research. For many newcomers the exchange of stories about field experiences is a valuable resource in learning to conduct research of ones own. Allegorical stories can also possess different meanings for different members of the audience. One of our informants frequently related a story about a volunteer field assistant she utilized in her field work:

I had this field assistant last summer, Bill, that came up from the U.S. to help for a few days. What a guy, he goes out with me to help collect lizards and in one day, ONE day, he must've pulled the tail off of half a dozen lizards. There was blood everywhere on the slopes that day. He was great at capturing lizards, but waaay too rough with them.

This story can be seen to have multiple meanings for different members of her audiences. For those who were helping her in her fieldwork, this story had the message ‘do not do this to the lizards.’ (We both heard this story many times making us particularly cautious in our own attempts of capturing lizards.) For researchers who used volunteer assistants in their own work the story was a cautionary tale with the sense that you have to ‘keep an eye on your field helpers, choose help carefully.’ This story was often in response to similar stories from other researchers about the problems of using field helpers. Our informant frequently discussed with us her own experiences with field assistants, how some were helpful while others constituted more work than if she was on her own. She accepted them as volunteers for the sole reason of maintaining “good community public relations.”

Allegorical stories that *inform* research practices of old-timers and researchers *in formation* also involve research aspects other than data collection. The field note excerpt describes a situation where a story was told again and, in this, obtained a particular salience to those present.

July 22: Sam told a story about inappropriate causal attributions she had heard told by a methods professor at her university, “one of Brad’s favorites about somebody getting data from veterinarians about injuries sustained by cats and the heights they were dropped from concluding from the data that if the cat drops from high enough then it reaches terminal velocity, doesn’t feel like it’s falling, and relaxes so that when it hits it doesn’t sustain much injury. <then strongly> Think about the biology of it, most times the cat is going to be so injured when dropped from a high height that the people wouldn’t even take it to the vet. Think about where your data’s coming from!! And that was a published paper.” [GMB field note]

Sam told this story because of her irritation with inappropriate causal claims that she heard both at conferences and from the undergraduates she taught. At the time we recorded

this note, it did not seem like much. We found out later that this tale was a reflection of the connections between individuals over time and space.

July 23: During lunch a comment was made, in the context of bears falling from trees on your head as a fear...“Imagine if it fell on you.” Sam replied, “Imagine if it missed.” I [GMB] then made the comment as a joke, “You know, bears can fall from a 10 story building without any damage because they reach terminal velocity and just relax.” which had Sam chortling and Stephanie asking where that comment came from. Sam explained the story she had told me the day previously and Stephanie [who attended a different university] said that it [the story about the cats] “was also Ron Taybor’s favorite story in class too, he must spend two periods on it.” Sam replied, “That’s pretty funny, because Ron Taybor and Brad [the professor from yesterday] did their graduate work together.” Stephanie tells us that Ron was her biostatistics professor at [her home institution]. Sam’s person yesterday was from [a different university]. [GMB field note]

Stories that are told time and again in a community encapsulate particular community concerns and interests. In this case there are two possible cautionary tales about conducting research offered here. The first relates to the general (scientific) concern of making claims of causality without proper consideration of the variables that might affect your results. The second is a warning about using (and misunderstanding) data which you did not collect yourself—an activity which field ecologists think that theoretical ecologists do as they model ecological situations. Thus, this narrative both cautions against making inappropriate causal claims and also contains an implicit critique of theoretical models not grounded in empirical data.

Formal conference presentations provide little *information* about field research methods on which those *in formation* could draw to guide their own research. There are, however, other opportunities at conferences to gather such *information* during *informal* discussions.

These informal discussions are an important resource for researchers. We observed that after the principal investigator returned from an international conference, many conversations over the next three weeks turned up *information* gathered there often in and from *informal* meetings. However, our informants frequently referred to such *information* as “anecdotal” because it dealt with topics unsubstantiated by formal observation. Nevertheless, these conversations influenced the research done by our ecologists. For example, in the following excerpt, Sam describes a conversation she had at the conference with a researcher who worked with pit vipers.

People don't think about the behavior of reptiles. They think it's not <indistinct>. I was talking to a guy at this conference and he was all excited. We talked and he thinks these guys show some maternal care. For about the week following birth of the young. And he's real excited. He's just discovered this in snakes. It's not, it's not like the birds but, you see lizards that will lick the young after they've given birth to them and they'll spend some time. He presented a paper on pit vipers, they're a kind of rattlesnake, and they stayed with the young for about a week until the young [have] had their first shed, which they have within a week. And they stayed with them. And uh, and this has never really been reported at all. Nobody's ever looked at this so he's all excited and stuff and we talked and he got me all excited about the lizards. I want to expand their homes and build some area so I can watch them so that's one of the activities for the next few weeks. Set up areas so I can watch them and get some data on their behavior. . . And Larry was all excited about this when he talked and I got all excited because he looks at behavior in snakes. . . I still think it would be neat to do this movement stuff first and we can get some idea of what areas they're using and then supplement that with behavior but the maternal, the behavior associated with the partition and birthing would be easy. It would be totally easy to collect that data so I think I'll set up those and if it

comes close I might move them home [to where I'm staying] or I might move out to the trailers [where the lizards were kept] or something and just like monitor them.

[Transcript of lunchtime discussion, GMB]

The enthusiasm of both belies the detached stereotype of the scientist promoted in science education reform documents (e.g., AAAS, 1989). Larry's suggestion influenced Sam who spent considerable time over the following weeks building new, much larger enclosures for her lizards. A discussion about an observed behavior in a species quite different from hers prompted Sam to reconstruct enclosures she had used in a previous field season and (plan to) engage in observations which were not at all central to her original research plan. During an interview seven months later at which she was providing a reading of some of her graphs, Sam commented on the value of "anecdotal" stories she heard at conferences and what they offered her:

And people, people seem to really like this species, it's funny...when I went to the meeting, lots of feedback, people, oh they tell you stories, of lizards, on and on, people get all excited. They've had, some have had the experience with it [her research organism], 'cause it's got quite a big distribution...so, they've, yeah, they've played with critters or know somebody that had them. Some guy, he grew up on Vancouver Island, so he grew up playing with them and they just, they like to tell lizard stories, they seem to get all excited which is fun 'cause it's really informative for me to hear lizard stories because they're all anecdotal but it's, it's interesting to jog some memories or to prompt questions or to reinforce observations.

Sam recognizes that the stories she hears, even those who do not work directly on the organism she studies, provide considerable insight into her own field work. *Informal* conversations contribute more than the *information* contained in *formal* presentations. Stories contribute particularly to the work of ecologists and help them contextualize their

own “anecdotal” observations. Several months later, Sam talked about the *information* she had obtained in an *informal* situation about maternal care in reptiles:

Larry was really helpful to talk to, this fellow that put me on to the fact that the pattern is probably a lab artifact, he presented some work on parental care. This is a phenomenon that’s been seen in fish but it’s not that common in reptiles, they simply drop them and bolt. And so he had some, done some work with snakes and suggested that this phenomenon existed and he had an alligator lizard in a tank in his office and he watched it give birth one afternoon and he was under the impression that potentially the mum was involved and so we talked at length and I did some observations on my guys to see if this phenomenon existed. So, I haven’t got back to them yet, I don’t think it does, as far as I can tell they just drop and bolt. But, yeah, it was really helpful for me.

This story about maternal care in reptiles, and how it developed and was elaborated in her conversation with Larry, obviously had considerable salience for Sam because she returned to it unprompted seven months later. In that time she had reconstructed her enclosures, structured her time so she could make observations on the lizards when they gave birth, and concluded from her “anecdotal” observations that maternal care did not exist in the type of lizard she studied. In this case, being able to observe a behavior never before reported in her species and the suggestion that a (distantly) related species might engage in the same behavior was enough to add a new research focus (though temporarily). Informal conversations therefore act as a considerable *information* resource even for researchers with more extensive field experience.

Informal public talks contained far more *information* about doing field research than *formal* presentations. They provided field researchers *in formation* with a greater resource for learning about doing research. An *informal* public talk about the bear research described above differed considerably from his *formal* texts on the same topic. Whereas the *formal*

texts presented variables as if they were pre-determined, interactions with bears as if they were benign, and little discussed field methods and experiences, the *informal* presentation were characterized by *information* on the methods used in conducting the research. This presentation provided details about how initial field observations resulted in a focus on specific features of the environment (in other words, how variables were developed), described in emotive tones the experience of working quite near to bears, and provided considerable *information* about how the data from which claims were derived was collected.

As with many of the *formal* oral presentation in ecology, the talk began with maps and diagrams that provided a geographic context for the research, rationales for choosing the locale, and the historical roots of the project. The initial stages of the study were clearly observational as the researcher developed his sense-of-the-field for that site.

So, what I was simply was doing in this first part of the study was document all of the species that utilized the salmon. And so, um, in the daylight um, every hour I'd make observations of the birds I saw, the number of seals I saw in the estuary, and I'd walk up the creek, record the crows um, what they were eating, and it sort of went on uh, day after day. So, when you put together the overall uh, wonders of species that we see in the estuary during salmon season you get sort of numbers for this particular locality of about 19 seals, 1 stellars sea lion, 8 black bear, and a bunch of loons, grebes and ducks, etc. coming down here [reference to an OH map], 375 gulls, approximately 4 species, and the other big species, 200 crows. Until you see all of these [indicating a pictorial representation on an overhead], using either directly the salmon, or the rotting salmon carcasses, or conceivably the eggs which float down the stream. You go out there week before [the salmon start spawning] and you seldom see any of these things. And you go there a week after

and you seldom see any. And so this is a real concentration [of organisms] in response to the presence of salmon. [Transcript from public talk]

This narrative provides those *in formation* several valuable pieces of *information*. These include insights on the frequency of observations, type of information to make note of (number of species, what they were eating), how long one surveys the area (“day after day”) and the length of time one stays at the research site (from before the salmon arrive until after they are no longer spawning).

Formal scientific texts present variables as if exist they existed a priori and independent of the knowing subject. Formal texts never suggest that in field research variables frequently emerge as scientists become familiar with the local setting. For researchers *in formation* this presents a substantial difficulty, for how should they decide what factors to examine in a setting they have not yet experienced? *Informal* discussions of research projects, such as the *informal* talk on bear research, provides a different perspective on variables in ecology research: they may develop as the study progresses. In the excerpt below the researcher talks about how field observations led to making a determination that was to further guide his data collection:

We began to focus on bears because they were one of the major consumers of salmon [at this site]. We actually looked for bears in the daytime and they’re not present in the estuary at all. From seven o’clock [a.m.] through to about three to four o’clock in the afternoon, no bear is ever on the estuary despite the prevalence and abundance of salmon everywhere in the estuary. Come twilight, rustle, rustle out of the forest comes the first bear, and five minutes after night you have the maximum number of bears feeding and throughout the night these bears are capturing salmon. [Transcript from public talk]

Having determined through field observations that bears consume more salmon than any other organism in the watershed and estuary, the project was narrowed to the impact of

the bears alone. In the previous description, a listener could learn *information* about bear movement patterns not at all present in the *formal* texts. The researcher then discussed human agency aspects of the research:

I have a lot of sort of anecdotal studies of observations of the [bears], that were sort of quite intimidating at first. In the daytime when you see a bear in the forest these bears will avoid you visually. They just do not like the sight of you and they do not like the sight of other bears so if they see another bear or if they see you they will try to walk around you just to get to you outside of their visual range. So you're accustomed to the bears giving you some leeway when they go [by]. At night-time bears don't see, but with your night-viewing glasses you can see everything. Well, these bears come, walk straight past you. <said with a bit of nervous chuckle> Obviously they have no visual component. They're cognizant of you from your smell, right? But they show no adverse response to you. They don't go around you, they come right past you. <nervous laughter in background>... The bears would rather pass me at close range, in spite of my potential threat, than step off their trails which are olfactory corridors. [Transcript from public talk]

This description provides considerable detail which elaborates the statement in the journal article that the bears were observed at a distance of "2m to 25m" (both this description and the one in this informal presentation are still lacking in detail compared to the bear story related in an even more informal setting). For new researchers this narrative is rich in detail about what a field ecologist might encounter when conducting research at night-time. Notable is that bear behavior at night is such that they: (i) cannot see well, (ii) perceive humans as a potential threat, (iii) will not avoid you if you are on their scent trail. For those about to conduct field research such information, not at all present in formal texts, is of considerable importance.

As is also clear from this passage, and as our field observations support, variables emerged in the conduct of the field research and as the study progressed numerous new variables emerged to the point that at least one new separate project developed from them. How new variables developed in the course of the study was contained in the narrative with such frequency that researchers *in formation* would have picked up on it. This contrasts with *formal* presentations about his work which implied that variable choice preceded the research.

Information provided in *informal* settings can also influence the conceptual understandings of researchers *in formation* and can thus guide future research. The following excerpts show how researchers *in formation* can learn from field observations on quite disparate organisms at different locations. Such *information* also provides insights into animal behavior and ecological principles:

In a bar a researcher was sitting and describing how, when observing bears and salmon at night time, he could wade into the stream and literally “pet” the fish without them moving, or at least moving very much. He said this was quite different from how they behaved in the daytime where they would be impossible to approach and reacted to any shadows or movement near them. He speculated that this might have something to do with the seals that were in the mouth of the estuary and the slight phosphorescence of the water which if moved through quickly would make the moving animal visible. [GMB field notes]

The researcher speculated reflected particular motivations behind the animals actions—of interest, but not the sort of thing reported in a *formal* journal article. However, individual field observations gain a broader salience and meaning when other individuals contribute to the conversation. In this case, a contribution made by another group member provided broader ecological context to the speculation:

Related a story about radio-tracking porpoises. . . and not being able to “figure out why they logged [seemed not to move] at the surface at night time until we had one in captivity in a large salmon net and watched him doing the same thing...and when he moved his outline was quite noticeable and sharks [a major predator of porpoises] might have cued in on this.” This individual also related being able to clearly see dolphins riding the bow wave of a sailboat on a dark, overcast night because of the phosphorescence in the water which outlined their body. [GMB fieldnotes]

This comment resulted in the conversation returning to the first speaker who strengthened his comment about the possible reasons for the behavior observed in the salmon based on the comments about the marine mammals.

Conversation went back to [the first speaker] about the salmon being afraid to move and that they must have known this went on [seals seeing the “glowing” fish] because if they were disturbed they’d move a short distance and then stop...which is not normal salmon behavior. [GMB field notes]

Thus, observations made of similar circumstances, although with different species, contributed to a broader sense of what was happening in nature. For researchers *in formation*, such conversations offer insights into how field observations lead to new studies and how knowledge claims develop in ecology.

Formal and Informal: Comparisons

This paper, unlike most papers in science studies about the construction of knowledge, focuses on the contribution *formal* and *informal* texts available in *formal* and *informal* settings make to the *information* of those *in formation*. Little work on the exchange of *information* by scientists in *informal* settings such as bars, parties, or over coffee has been conducted; previous studies of informal texts instead examined discussions held in the laboratory as work was being conducted (Lynch, 1985), explicit discussions of conceptual

issues (Garvey & Griffith, 1971), and *information* solicited in interviews (Gilbert & Mulkay, 1984). Unlike these studies, we observed our participants as they discussed their research in *formal* and *informal* settings unprompted by our intervention. From these observations we conclude that the formal and informal texts are fundamentally different in the information they convey about the conduct of field ecology research.

These conversational settings have some similarity to those which were examined by Orr (1990) as he participated in a community of service technicians. The conceptual setting of our work differs from this work in that the communities under study engaged in quite different tasks. Orr studied technicians who were engaged in repairing office equipment. They both knew what their purpose was (to repair machines) as well as what the indicators of success at that task would be (a working machine). In addition, the ‘focus’ of their work, a machine, was constructed of a limited number of parts that can experience a limited number of possible breakdowns.

At the end of four years of enculturation with *formal* texts undergraduate ecology students have been presented with the broad conceptual issues about which ecologists are concerned, but have few resources on which they can draw to plan and conduct field research. Students experience few opportunities from which they can learn that research is conducted (and papers written) as part of an inter-related series of investigations by a researcher or a group of researchers—this is almost never discussed in lectures and the structure of the laboratory exercises does not emulate this. In fact, school-based research activities (such as the one described above) and the structure of lectures develop in students a sense that the knowledge claims of ecology exist as distinct and unconnected bits (Bowen & Roth, 1998). Most crucially, lectures and other *formal* teaching situations do not provide students with a sense of how research is done. This lack of embeddedness extended beyond the decontextualized, impersonal, presentation of ecological truisms found in lectures and textbooks to the practice field research activities (the equivalent of physics and

chemistry laboratory exercises) in which undergraduate ecology students engaged. In addition, courses rarely offer students the opportunity to examine a series of papers from a single author which would help them develop the understanding of the embeddedness of individual research projects in the broader of the discipline and individual researchers. For example, the Science Citation Index provides evidence that the project on bears is embedded in a series of projects in that area over twenty years involving organisms at different trophic levels. In addition, collaboration with other researchers from other disciplines has allowed their tool-based practices and skills to be adopted for application to the broader ecological interests of the informant. Students have little guidance to aid them in observing research in this manner.

Many authors noted that a characteristic of most *formal* texts of laboratory science (Gross, 1996; Latour, 1987; Nespor, 1994; Traweek, 1988) is the removal of all aspects of agency of the actors. Thus, through this stylistic structuring, greater authority is attributed to them because of distancing of the subjectivity of the agents involved in their construction (Gross, 1996). This authorization of *formal* texts is enhanced by the manner in which the research is discussed ahistorically. The ahistoricity of the presentation in *formal* texts of knowledge claims and variables is problematic for those *in formation* planning their own field research. The absence of a sense of the passage of time provides those *in formation* little understanding of how experienced researchers frame and develop their understanding. This includes the understanding of problems, how the concerns of the discipline change, and what variables are important in doing the research.

The *formal* texts of science present an objectivist perspective of the claims and processes as if they were purely factual (Gilbert & Mulkay, 1984). This differs from *informal* accounts of field research which has a decidedly contingent character. The degree of detail in *informal* texts about field practices (how observations are made, how features are considered important enough to warrant being defined as a variable for study, and how

interpretations change over time) is not found in the *formal* texts. Discussions of field research in *informal* settings present this *information* differently than *formal* texts. Little or no discussion of this occurs in *formal* texts. These *informal* texts (and our ethnographic work in the field) reveal that data is collected because the opportunity arises for it to be collected, not because there is necessarily an immediate or conceptual reason to do so. Thus, the *informal* settings provide context and *information* about field research unavailable in *formal* texts to researchers *in formation*. For new (and old-timer) researchers detailed descriptions of field work constitute a useful resource informing their own (future) field research work. *Informal* settings provide this very sort of *information* within the narratives exchanged as researchers talk about their work and discuss their experiences.

In addition, the underdetermined nature of the *formal* texts has more significance for researchers *in formation* than for experienced researchers. Experienced researchers can draw on their own experiences to contextualize the *formal* written texts but those *in formation* have to rely on the text itself; so that which is unstated in those *formal* texts, available in some sense to experienced researchers as they use their lived experience to make sense of their readings, is unavailable to those *in formation*.

B(e)ar Talk and Social Cohesion

Interactions and storytelling in *informal* settings are quite important to ecologists for reasons other than for research purposes alone—ecologists seem to form a network of acquaintance that is based around the exchange of stories. Stories appear to reinforce this network of acquaintance in several ways and contribute to a social cohesion amongst ecologists. Within *informal* settings stories of work in the field are told over and again which contributes to a cohesion between members that crosses more than just the immediate group of participants. Being a member of this community means being able to participate in those stories in diverse settings as one meets unfamiliar ecologists when travelling or conducting your own research. We noted that several aspects of *informal*

discussions contributed to cohesion (as well as being resources for new researchers): discussions about individuals, discussions of common experiences, discussions of experiences across which ecological parallels can be drawn, and discussions of common (ecological) cultural touchstones which have salience to community members.

Social cohesion develops when individuals can find common ground in their interests and narratives. The excerpts related earlier represent one way in which stories contribute to social cohesion—by offering the opportunity for individuals to find examples of persons they know in common. In addition, such widely shared stories contribute to social cohesion by providing narratives which communicate concerns and issues of the discipline in a manner accessible to any member of a group in which the story is discussed. Thus, exchanging stories allows ecologists to form a community not just of practice and concerns and language, but also of social experience—our work suggests that the social interactions outside of work hours are of considerable importance in becoming an ecologist.

During our ethnographic work who-knows-whom was a frequent topic of conversation in *informal* settings. We noted that individuals who conduct field research, even in unrelated topic areas, are often broadly known. Researchers were known and talked about because of ground-breaking research they had done in the past and were commented upon in conversation in the context of talking about individuals who had influenced their own research work. In one case an individual who did graduate work with turtles in the mid-1980's was known by ecologists who worked with lizards, migrating ducks, snakes, tree ecology, and minuscule insects. We also noted that knowledge about various individuals and being able to relate tales of that work appeared to be a keystone factor which allowed us to be accepted into groups of ecologists. We were struck by the wide connections which existed amongst ecologists for it was a rare group within which there was not at least one common acquaintance. Clearly, part of his acceptance into groups of ecologists was

because Bowen could claim prior acquaintance with other members in the network of ecologists.

Story-telling, and the topics and individuals about which those tales are told, provided us access into even newly-met groups of ecologists. In this, as we noted earlier with inexperienced researchers, it was not sufficient to merely have experiences to tell, but to be able to relate them in the context of the work of others that was important. We observed newer graduate students, over many months, at first sit quite quietly in groups, and then begin to contribute field-based narratives into the context of the conversations. As noted earlier, this rarely happened when they were just in groups of MSc graduate students (they did not try out their stories in settings of peers) but instead usually occurred in discussions at which professors and PhD students (and post-doctoral researchers) were also participating.

In part, social cohesion develops because of experiences shared in common not directly related to research but arising as a consequence of engaging in field research. For instance, whether one is concerned about ecology of a particular lily that grows on the edge of meadows, studies lizard biology, is interested in insects which grow at the top of 30-meter tall trees in rainforests, examines distribution and breeding of woodpeckers, or is interested in the utilization of spawning salmon in coastal streams—quite diverse ecological topics—there are stories which are based in the common experiences of those respective individuals which can be related amongst individuals in those projects.

Informal settings also offer ecologists the opportunity to share observations which they refer to as “anecdotal,” in other words, observations which are not sufficiently substantiated to warrant publication. Our observations during *informal* conversations suggest that these conversations help ecologists make sense of their anecdotes in a broader ecological context by providing a forum for people working on different organisms or in different biomes. For instance, the observations regarding salmon behavior at night-time in

the estuary and porpoise behaviour are not related in any *formal* texts, and were not mentioned even in the *informal* verbal presentation. Yet, sharing these observations helped develop understanding of ecological relationships. For researchers *in formation*, these anecdotal conversations would contribute to their understanding of the development of scientific claims.

Many of the stories that contribute to social are heroic stories because they relate unusual accomplishments and dangerous encounters. Although these heroic stories occur to some degree in other *informal* settings, they are notably frequent in bar settings attended by mixed groups of researchers. In these settings stories about getting into street fights in foreign countries, dangerous situations in remote areas, and survival in adverse conditions are common. It is not surprising that much of the stories involved bear because of the geographic location of our research groups and the wilderness settings in which they worked. Thus, in bar settings stories about bear/salmon research included details not provided in other forums:

Told the people in the bar (when stories were being traded) about having bears brush up against him, when he was observing them at night times, as they rushed to the stream to get to the salmon. He talked about how unnerving this was at first but that the bears seemed to ignore him completely because of their focus on getting to the stream. [GMB field notes]

In this most *informal* of settings, we heard stories about working with the bears and salmon unlike any of those related in any of the verbal presentations or formal writings about the work. For researchers *in formation*, this is a view of research unavailable in other contexts. In contrast to his *formal* texts, our bear research related how nervous he was initially. In the public talk he told how close he came to the bears and how he could see them with his night glasses but that the bears were unable to see him. In the bar setting, we first heard him talk about the initial stages of the research when he saw little after night fall

but felt and heard the bears close at hand. What our words here communicate poorly is the intensity of the feeling he had about those encounters—the initial perception of danger was communicated in his voice unlike that in any other setting.

Heroic stories about bears are not just related by the researchers engaged in bear research, but are common currency in the stories of field research, as the following field note suggests. These heroic stories also contribute to the social cohesion of the ecologist community.

She then related another short story. . . about another time a bear was “that close” (3-4m) and how she made a loud noise to scare it off. RR related that the “biologist in me just wants to watch,” but then she realizes the danger and makes a loud noise so the bear knows she is there. Nat then related a story of spraying the bear that was “this close” <indicating 2 m> away [Analytic note: he also related this story over coffee a few days ago]....then followed it up with a story about walking along a trail towards his quad [a bush vehicle] and then “I noticed THREE PATCHES OF BLACK up a tree, THREE cubs. I froze, and then looked around. I couldn’t see the mother anywhere, but didn’t know where to go. I didn’t know what to do. If she was behind me (and away from the quad) then I’d walk into her and be between her and the cubs. If I walked towards the quad then I’d be walking towards the cubs, also not the smartest thing to do. I debated whether to cut off into the woods off the trail and circle around, and that’s what I finally did. At first when something like this happens you think about getting your camera out of your backpack because it would make a neat picture. And then you realize that would be stupid, that you’ve got to get out of there.”

These heroic stories were present in other settings as well, but the social groupings in the bar (where professors sat with graduate students more so than other places) appeared particularly conducive to the relation of harrowing stories of survival and danger in field

settings. What is significant about these stories is that while some stories were told and re-told autobiographically, others were re-told by individuals who had heard the stories from another ecologist. Thus, these stories, much as those about well-known individuals constitute some of the cultural capital that constitutes membership in the community of ecologists. By learning, and being able to re-tell, these stories new members are enculturated into the community and thus gain access to the pool of knowledge and the individuals within it who share these common experiences and stories.

Discussion

Becoming a member of the community of ecologists is more than becoming a member of the community of practice for being an ecologists means more than just engaging in field research and interpretive practices. The stories and other *informal* exchanges within ecology provide substantial resources for new ecologists to draw upon for their own work—often unavailable in the formal texts of ecology. However, *informal* settings and the narratives related in them also embed new ecologists in a social framework of experiences and activities apart from the academic ones. Unlike office workers who go to the office, do their job, and leave, participating in ecology as a researcher includes the social gatherings (Friday beers, Wednesday pool, conference drinking) as much as it includes doing research.

Undoubtedly, part of the reason for differences between the content of *formal* and *informal* oral presentations was the amount of time and space available; the *informal* talk was eighty-five minutes in length compared to *formal* conference presentations are typically fifteen minutes long. However, the ecology lectures we observed were fifty minutes in length and yet rarely discussed field research in the manner it was presented in informal settings. This suggests that the differences in content reflect an epistemological view that students are there in a lecture to learn the knowledge claims of ecology and not about

“anecdotes” of field practices—even though field researchers themselves recognize the importance of anecdotes to the success of their work.

Traweek (1988) concluded that “knowing the stories and performing in the appropriate style is an unmistakable sign of being a real particle physicist, of knowing particle physics, and of knowing how to make knowledge of particle physics” (p. 121). However, her descriptions of the stories suggests that they are often highly technical using specialized language and that the conversations frequently dealt with learning what new claims are made and what new techniques are developed in the discipline. In this, the stories of physicists differ from those told among ecologists which often deal less with knowledge claims and more with doing research; how someone deals with a research problem or survives a dangerous situation. Nevertheless, the outcome of this “gossip” amongst high energy particle physicists seems similar to what we note in ecologists: it helps structure and connect a small, geographically diverse community. However, whereas stories among particle physicists are used to control who is (to become) a particle physicist, being able to participate in the stories is one of the ways in ecologists are accepted. *Informal* settings contribute substantially to the success of field research. This needs to be considered when educators examine and plan the programs for those *in formation*. Divisions that occur in post-secondary institutions between undergraduates, graduate students, and professors are clearly counter-productive; for the most substantial resources of *information* on field practices, experienced researchers, rarely interact in *informal* settings or socially with those who are about to engage in their own work.

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Chapter 11:

Biology as everyday social practice: Pedagogical implications

Biology as everyday social practice: Pedagogical implications

Abstract

Traditionally, science has been primarily viewed as a body of knowledge which needed to be transferred to (or reconstructed in) the minds of students; this body of knowledge was thought to be complemented by scientific skills which students acquired by doing standard (recipe-like) laboratory exercises. Recent investigations of biologists in the everyday pursuit of their work revealed a different image of what it means to know biology. Knowing biology turned out to be constituted by complex lived and embodied experience which biologists appropriated by participating in the practices of/with more experienced peers. Much of what makes a biologist are currently learned *in praxis* and *after* completing school and university. In this paper, we outline a theoretical framework undergirding our research agenda concerned with engaging school students in everyday scientific practice and thereby learning through participation. Our argument is illustrated by examples from empirical studies of knowing and learning biology from middle school to professional science. We discuss implications of this framework for achieving our ultimate goal; the design of learning environments in which individuals move along continuous trajectories from their initial school experiences with biology to full participation in biology as everyday practice (as scientists, environmental activities, informed citizens, etc.).

Traditionally, science has been presented, at least in the public view, as a rationalistic enterprise whose purpose is to generate understanding of natural phenomenon through the discovery of “truth claims” or “facts.” School science has paralleled this conception with its approach to curriculum—if science was about the discovery of “facts” then a solid knowledge of those facts was necessary for an agent to “know” science. This traditional view of science, often held by student teachers (Haggerty, 1992), is implicit in how much science is taught; it is also embodied in formal curriculum directives such as the National Standards or the British Columbia Integrated Resource Packages. This means that science students’ education experience often leads them to develop an objectivist conception of knowledge—understanding science as a collection of facts (Brookhart-Costa, 1993; Poole, 1994) and only rarely experiencing any of the “messiness” which characterizes everyday science. An examination of textbook science reinforces the perspective that science is taught as if it is made up of sterile facts which have been discovered (Kuhn, 1970; Latour & Woolgar, 1986). Textbook readings and lectures—vehicles for transmitting content—comprise much of how students learn about science in North America (Lemke, 1990; Tobin, 1990), which has significant implications for what it is that students learn about what “science” is (e.g., Bowen & Roth, 1998a). Students who study science from textbooks or use cookbook labs often develop an impoverished view of theory and the practices of science because they are unable to contextualize it in their own experience. Further, engagement in traditional school laboratory activities, in which students follow step-by-step procedures to achieve a specific outcome, result in students who learn procedures rather than develop their understanding of scientific practices and claims (Amerine & Bilmes, 1990).

As former research scientists in biology and physics, we know that “science” is much more than the accumulation of written texts, “standardized procedures,” and representations typically presented in science classrooms. The following scenario illustrates the

complexities of scientific interpretations of inscriptions and the claims which arise from these interpretations. This scenario was constructed⁹⁴ from interviews with eight ecologists who provided their interpretations of a graph (Figure 1) used with students in a second-year introductory ecology class at a university in western Canada (Bowen, Roth, & McGinn, in press) and from our ethnographic work with ecologists in their laboratories, classrooms, and in the field.

Todd looked down at the page of questions on Donna's desk beside his in the sessional instructors' office. She was teaching introductory ecology this semester and had prepared questions for the students to work on in their seminar. Todd read over the question (see Figure 1) where a graph showed a population death rate increasing linearly as a function of N and the birth rate followed a quadratic function. "Discuss the implications of the birth and death rates as regards conservation of such a species." Todd pondered how he would answer the question. . . . "The intersection points indicate some type of theoretical equilibria and the population would crash to zero if the population size dropped below the first intersection because the death rate would be higher than the birth rate. It's deterministic? But populations don't do that do they? I know several that haven't, like the California sardine—the animals re-clustered into a smaller area. So the N doesn't represent population size but rather density. Or does it? Nothing said about that. But of course, it is a theoretical equilibrium. In my field work lemmings decreased their home range when population was low and clustered in better food areas. So for me I'd use the graph to predict how animals might behave at different population sizes. But Donna is a theoretical ecologist so maybe she's using it to illustrate factors that affect population size, and birth and death rates. I guess it

⁹⁴ We use a constructed scenario to effectively and efficiently summarize information commonly present in interviews and observed in interactions between community members.

could be used both ways. Her way would suggest that we should be concerned about keeping a population safely above the first intersection so that the population doesn't crash. Hmm. That's like the cod on the east coast. I wonder if that's what happened there?"

[Insert Figure 1 about here]

In this scenario the interplay between the concerns of a theoretical ecologist and a field ecologist are played out as Todd reflected on the question. The different “lenses” of theoretical and field ecologists leads to a consideration of different issues such as how animals would behave compared to how a population size would change. The graph is shown to have different uses, and therefore, as Wittgenstein (1994) argued, different meanings to different people—which then influences their subsequent conclusions about and uses of the graph. Even between scientists from the same discipline, such as field ecology, there were differences in interpretation (Roth, Masciotra, & Bowen, 1998). A theoretical ecologist, whose discourse resembled that of another physicist in our study, discussed the mathematics behind the graphical representation as a “conceptual framework” to guide further population ecology issues. Both of these scientists, as well as a small animal ecologist, discussed the graph in deterministic terms. Reflecting other concerns and practices, a large-animal ecologist discussed the graph as being suggestive of change (as opposed to deterministic) because its outcome was mediated by “animals being able to behave.”

Our research with practicing scientists shows that involvement in different disciplines influences the “lens” through which one interprets that which might commonly be thought of as being unitary in meaning. For instance, scientists with different academic foci were found to interpret the same graph Todd and Donna considered in the scenario in quite different ways—and to reach quite different conclusions from the graph, which varied with the concerns of their (sub-) discipline and the resources on which they drew (Bowen,

Roth, & McGinn, in press). Based on what we have said so far, readers may not be surprised that the physicists' interpretations and practices were significantly different than those of the field ecologists. The physicists, when asked to interpret the graph, reflected a central concern with generating better representations of the graph; with their new representations, they attempted to show more clearly a system which had a point of stability and a point of instability. To do this, one of the physicists drew on his knowledge of stable state systems in chemistry and physics and, using mathematical resources and tools available to him, used Mathcad™ to create a clearer representation. Only at this point did he proceed to interpret the graph.

Such diversity in “correct” answers for this graph (documented in greater detail in Roth & Bowen, 1999) differs considerably from traditional research work on graph interpretation which has focused on respondents reaching (or not reaching) a unitary interpretation (see review in Leinhardt, Zaslavsky, & Stein, 1990). It also differs from how graph interpretations by students are dealt with in most school science. Whereas graph-related activities in school science often seem to assume that there is only one right interpretation, our research showed that scientists may interpret the same graphs in widely differing ways.

Overall, we found that scientists' concerns, resources and ultimate claims were based on their enculturation into their sub-discipline and that their interpretations of representations, such as the animal population graph, was rooted in their understanding of graphs that developed in their own production and use of graphs in their own research. Our ethnographic observations suggest that these skills develop in the context of participating in forums in which their (graphical) work is presented, open to critique, and defended to both peers and “old-timers” (Lave & Wenger, 1991). Further, we found that competency in scientific practices is “flexible”—for instance, scientists can have difficulty interpreting even ‘simple’ graphs if their context lies outside the scientists' experiences which would

allow them to relate the graphs to their own practices (Roth & Bowen, 1999; Roth & Bowen, in review).

If scientists themselves have difficulty understanding scientific practices and procedures without guidance from and apprenticeship with “old-timers” who have experience with them, it is difficult to see how students can learn the interpretive practices of science without engaging in activities which allow them to develop resources to draw on—including the tacit knowledge accumulated through engaging in activities somehow congruent with those scientists. We therefore argue that teaching biology effectively requires a shift from pedagogy rooted in the information processing or constructivist metaphor to one which encompasses the notion of knowledge as practice. A different understanding of the practices of field biology leads to a necessity for different approaches to teaching biology so that students are able to best understand and utilize the knowledge claims of biologists. We present evidence of the practices of field biologists by drawing on our two-year ethnographic field work with and among them. We then detail two studies in which we used different approaches to engage students in using science as a tool to develop their understanding of biological issues.

The Practice of Science

“Doing” science involves conducting research studies that are “do-able” and which give results (Fujimura, 1992; Knorr-Cetina, 1992) and then making arguments about the meaning of the data derived from those studies so as to convince others about the meaning and importance of those data. To achieve that end (i.e., making convincing arguments), scientists operate within a “culture” that is discipline (and sub-discipline) specific. That “culture” of science can be discussed (as can that of any other profession) from the perspective of examining its ongoing concerns, standardized practices, resources (both linguistic and tool), and breakdowns. Taken together, concerns, practices, resources and breakdowns present an ontological map of the domain which can be thought of as “a

conceptual framework for interpreting the world in terms of recurrent action” (Denning & Dargan, 1996, p. 117). Several of these components of the ontological map are apparent in the above scenario and represent a melding of the individual’s personal views in those areas and those specific to their domain. The person in the above scenario is a scientist, but the ontological map one could derive from the scenario is not representative just of “science,” but also of the sub/discipline of science in which that person participates in. In highlighting the different concerns of “Donna” and “Todd” in the scenario, and how that influences the interpretation and use of the graph in question, the influence of even minor differences in the ontological map in defining sub-disciplines becomes obvious. It is important to realize that neither interpretation of the graph offered is “incorrect”—within the represented sub-disciplines both interpretations are internally consistent and are, therefore, “correct.”

Over the past 20 years, science studies research has resulted in considerable insight into how scientists conduct their work and establish scientific facts, artifacts, and theories. For instance, this work has reported that the claims made by investigators are accepted by the broader scientific community through socially mediated processes both in their discovery in the lab and in their acceptance in the broader community. In addition to this social mediation, science studies research showed that the development and interpretation of given scientific “facts” by scientists are influenced by the concerns, resources and practices of the sub-disciplines of the scientists involved (Knorr-Cetina, 1981; Latour & Woolgar, 1986). These studies reveal a “messiness” involved in the conduct of science—both in the “discovery” of something in the laboratory and in the process through which the claims are presented to the broader science community in journals and how these come to be accepted or rejected—that contradicts how the broader public generally perceives science to occur and scientific decisions to be made. Having done research in science, and most recently conducted ethnographic work with ecologists ourselves (Bowen & Roth, 1998b; Roth &

Bowen, 1998) we can confirm these descriptions of science studies. Well known scientists such as David Suzuki (1989) lend further confirmation to these descriptions.

For instance, most “just plain folks” (Lave, 1988) view “facts” as objective statements that reveal some essential, incontrovertible characteristic of nature. Science studies suggest, however, that scientific ideas move up a “ladder of facticity” from being considered the work of particular investigators to being determined by “nature” not by the work of investigators (Latour, 1987). Thus, scientific observations take on a “facticity” which make them seem an inevitable part of nature once they are accepted by the scientific community rather than revealing objective “essences” of nature (Latour & Woolgar, 1986). This move up the ladder is socially and culturally mediated along its entire path as the claim is evaluated and challenged by others in the scientific community. The fate of the claim, regardless of the objectivity of its comment, is dependent on the behavior and evaluations of others:

You may have written the definitive paper proving that the earth is hollow and the moon is made of green cheese but this paper will not become definitive if others do not take it up and use it as a matter of fact later on. You need *them* to make *your* paper a decisive one. If they laugh at you, if they are indifferent, if they shrug it off, it is the end of your paper. (Latour; 1987, p. 104)

Throughout this, the people who “read” a paper place its argument and claims in the context of their own experiences and use those resources as the basis for addressing commentary and criticism.

Our research with graphing (e.g., Roth & Bowen, 1999; Roth & Bowen, in review) suggests that embodied meaningful experience is necessary to be able to interpret and evaluate knowledge claims that are made by others. This holds true for other scientific

practices as well. For example, an attempt to conduct PCR research⁹⁵ was stymied when a researcher had only a procedural manual and other textual material as guides. The researcher was successful using the PCR amplification technique only after another lab, which was successfully using the technique, was visited and the technique demonstrated (Jordan & Lynch, 1993). This study also showed that it is difficult to run successful PCR assays even with experience. Such difficulties in the conduct of genetics research are not uncommon. In an agricultural research laboratory, efforts to obtain and transfer DNA from pesticide resistant bacteria to alfalfa were inconsistent and unsuccessful, despite careful attention to published papers and procedural manuals, until other laboratories using such techniques for other purposes were visited and techniques practiced with scientists who had successfully conducted such a transfer (Bowen, unpublished data). In this work it is clear that laboratory practices are so contextually contingent that scientists sometimes cannot transfer their own practices from one lab to the next: although they used an analytical technique successfully in one situation, the same technique does not work when they move to a new context (Knorr-Cetina, 1981).

The necessity for learning practices from those already successfully versed in the practices, despite those practices being written about extensively, occurs because the procedures and practices of science are underdetermined by any description. This occurs partly because the context of events being described is often unavailable making clear the importance of prior participation to help provide context when interpreting written materials. In this sense, “context” includes tacit knowledge which cannot be conveyed in journal articles (Knorr-Cetina, 1981) and which must be gained through practical experience. What it might mean to appropriate tacit forms of knowledge through

⁹⁵ A laboratory procedure in which a small amount of a DNA sample can be “multiplied” (the strands replicated) by orders of magnitude so that sufficient quantities exist to permit the conduct of chromatographic analysis techniques allowing identification of individuals (etc.) through the presence of marker genes.

participation in the everyday practices of research science is illustrated in the following description of ecological field work from our own ethnographic work.

The Everyday Practice of Biology: The Natural History of Lizards

Overall, social studies of science research (ours⁹⁶ and that of others) led us to the conclusion that science is not the sterile, clean process that many believe it to be. The knowledge of scientists is personal—developed and defined by their experiences—and is subject to many social influences not commonly thought of as being part of the how science “facts” come to be. At the same time, it becomes apparent that the knowledge of individual scientists, their ability to interpret the journal papers which leave out much of the discovery process (Knorr-Cetina, 1981) and the knowledge claims of other scientists, is based on their tacit and embodied knowledge arising from being involved in the process of constructing personal and public knowledge. To illustrate this we will draw on the ethnography we conducted with field ecologists over two (of their) field seasons.

Sam and her research assistants started hiking down the wooded path. In thirty-five minutes they would reach their research site and begin a new phase in trying to understand the natural history of striped lizards. Over the past four days they had traversed the slopes, capturing (and missing) lizards by hand. The capture locale was “tagged” with a number on a spike and those lizards which were caught transported back to the laboratory at which they were weighed, had their appendage and overall length measured, and timed running down a track. However, those (and other) measures of individuals now had to be related back to the environment from which they came, and that was what was now beginning. Last year she had only

⁹⁶ To investigate the practices of field ecologists we participated in different aspects of their community over two years. During this time we conducted ethnographic research as participant observers in their field research over two field seasons, conducted a video-ethnography of a second-year ecology class, attended numerous departmental seminars, conferences, and workshops, and conducted interviews with ecologists about their field practices and interpretation of the work of other ecologists.

measured a few things, but this year, after conferences, conversations with other researchers, and suggestions from her field assistants, Sam had decided to expand the number of factors she was going to record: distance to the forest edge, distance to the nearest (and type of) shrub, direction the slope was facing, distance to the nearest rock, distance to the nearest rockpile. . .

However, the details of these measurements were unspecified in initially considering what was to be measured. At the first and second locations where lizards were caught and at which measurements were made these distances had to be operationalized in a manner which allowed the wide variation in possible meanings of terminologies to become “do-able” in the field measurements. This is detailed in the following excerpt from the ethnographic fieldnotes recorded by GMB:

Measures to the nearest shrubs and to the next closest rocks are done because they are cover objects to which Sam expects a lizard to run if they are disturbed. Sam has decided that the rock has to be one ‘that a lizard could run under’ so it must be moveable and have visible areas that one could run under. It also has to be ‘at least 10cm across so it can be a suitable cover object.’ What was a ‘shrub’ was also unspecified until we. . . . had to deal with plants that were technically “shrubs” (according to our field guide) but which didn’t offer any possibility of cover to a lizard. At that point they were more clearly specified as being about “that far apart” (holding hands apart) at the base, which was decided to be close to a meter in width.

Even so, which rock was the “right” rock to measure and at which point the “base” of the shrub should be measured was discussed amongst the field researchers for most sites. These needed to be negotiated, however briefly, at each place because of the lack of any external labels or indicators provided by others—there were no “step-by-step” instructions or explicit “authority” removing the ambiguities of the work such as is found in typical

classroom settings. Specification of what artifact was to constitute the correct place to which to measure distance, what criteria were to be followed, and even what variables were to be considered emerged as the field work progressed.⁹⁷ The measurements taken in the field were recorded in tables (e.g., Figure 2a) which were later, usually that week, inscribed as scale maps (e.g. Figure 2b) which could then be examined for patterns relating where lizards were found to the various variables identified as being important.

[Insert Figure 2 about here]

Despite the considerable amount of effort which went into collecting the data which was inscribed on the maps Sam was quite unsure whether they would be of any use or help to her formal analysis and writing. Nonetheless, she spent her evenings moving the data from the tables onto the maps because the maps represented a tool which helped her think about her field research problems. By looking at the maps she could picture the areas where the lizards were caught and think about new problems to be considered or new variables to be measured. One example of this occurred between the two field seasons we observed when Sam decided to specifically measure the angles between the various sites at which lizards were caught instead of just “eyeballing” it. Between seasons she had found that working with her maps was more difficult because she had initially chosen the latter approach. Because she had marked the capture sites, it was simply a matter of going back to the field sites, locating the markers, and measuring the angles with a compass.

In our ethnographic work, we were particularly interested in the construction of facts in field ecology. Many field ecologists understand themselves as doing observational science operating without grand theories or narratives to guide their work. The “facts” they report in academic settings (posters, presentations, articles) are purely based on *measurements*,

⁹⁷ Preliminary work suggests that this lack of external “authorities” on which to rely for confirmation and affirmation of their procedures and analysis techniques is a source of considerable stress and dissatisfaction for new MSc students who are used to conducting biology techniques/research based on the clear instructions and guidance found in their university courses. Several respondents identified this contrast as a reason for students dropping out of the program.

although our work showed that much of what ecologists know is derived from *naturalistic* observation. Yet, these measurement data are diverse in their origin and error size and are collected over a considerable geographical area (here a 20 km stretch) and over long periods of time (3 years). To coordinate these diverse data in time and space, considerable work has to be done by each ecologist before individual data can be converted into population statistics and subsequently reported in academic settings. Along the trajectory from data to reported fact, ecologists are not always certain whether they have observed something. The following quotes from different stages in the construction of one lizard species illustrate such uncertainties.

I usually find about five [lizards] a day. I sort of am getting this feeling that they are more active later in the day. They can't tolerate, I think preferred temperature is about 20, mid 20's or maybe high 20's. Probably mid. So in the real heat of the day I don't look for the animals 'cause they're buried down too deep and then I go out again in the 4 to 6 kind of range and lately I've noticed I've had better luck'.

I don't know if I will be able to use these speed measures, but I do it anyway.

Maybe there is something, maybe not.

And it turns out the longer the lizards are kept in the lab, the slower they run.

Which is kind of interesting, but I can statistically control for this effect and go on to look to see if there are other things that are important. And it turns out there are.

One of the things that's important is what sex you are. Adult males are typically shorter than adult females, their body lengths are shorter. And adult males also have relatively longer back legs than adult females. And it turns out that this body length and back leg length is important for predicting how fast it runs.

Similar to the solidification of facts as described by Latour (1987), we first see uncertainties of finding lizards and whether the sprint trials conducted with the animals Sam captured and returned with to the field laboratory were any good. Later along the research

process, and especially far away from the field in a more formal academic setting, we see Sam again, but her knowledge now has the matter-of-factness of propositional knowledge. Lizards are given in terms of correlations between sprint speed (dependent variable) and body length and back leg length (independent variables). At one time during our study, we see uncertainties related to objects, instruments, and measurement processes in the field; at another time we see factual statements and hard inscriptions.

An anthropologist of science who works backwards and traces the statements and data, would find printouts from statistics software that had operated on a large database, which itself was imported from a spreadsheet software package into which numbers had been entered during the ecologist's past field seasons. If our anthropologist went further, she would find a proliferating number of inscriptions: field notebooks; tables partially filled with records of widely varying origins; forms; printouts containing codes and coding schemes; numbered metal tags for field use; labelled and code-bearing vials, socks, plastic holding boxes and wooden enclosures all identifiable by a one- or two-digit painted number. With each inscription, she would also identify an array of diverse instruments each associated with different sets of measurement practices. Surprisingly, she would find little in terms of concepts, laws, and theories but, as her participants would tell her repeatedly, "a lot of conceptual mayhem that lies beneath all of that."

In our observations, much of the ecological fieldwork appears to be driven by what is do-able in terms of measurement. Furthermore, there are also considerable variations in measurement practices, scales of measurement, and measurement error. That is, ecologists' activities and the resulting data on which their claims are built arise from structurally variegated observations associated with considerable work coordinating the data which leads to the emergence of the "lizard" as a scientific object. Thus, the lizard has become visible. But it is not *just* a natural object, not *just* an individual construction, and not *just* a

social construction. Rather, the nature of our “lizard” arises from the interaction of nature, individual, and culture and from a “mangle of practice” (Pickering, 1995).

Our ethnographic work with Sam and her assistants led us to understand that, unlike other disciplines, much of biology field work is less theory-driven than it is emergent, both in the framing of what is a “problem” to be addressed and what methods will be employed to address those “problems” which literally arise when conducting the field research. Our interviews with and observations of other ecologists confirmed that our observations during the extended ethnography with Sam are typical for the conduct of field ecology research. This emergent aspect of field science differs substantially from the view of biology research gained by students in most science classrooms. This suggests that if students are to understand the claims of field research, which underlies most aspects of ecology, animal behaviour, and natural history investigations, then they must themselves engage in those field practices.

From Professional Research to School Biology

All of the decisions about protocols, variables, etcetera made by Sam and her field assistants are not evident in the writings and formal presentations about the field work—which is entirely consistent with the writings about field work in biology in general. In fact, the presentation of biological field work in its writing (whether to university or public school audiences) leaves unmentioned any of the hesitations, contingencies, and uncertainties voiced by biologists when in the field. Clearly, the experiences of this type of work are undetermined by the text and representations which do not at all communicate the emergent and contingent nature of the decisions made while conducting the research work. Thus, basing approaches to teaching biology on the factual claims and stated methodologies of the discipline, which is what we have done in the past, misrepresents the conduct, analytical approach, and “facts” of the field-based sciences.

Implications of Work of and in Science

Given our new understanding of science and its processes of discovery and defining scientific “facts,” the question is raised “How can one become best enculturated into these practices?” Cole (1992) argues that the insights of the micro-level social constructivists into the social processes of science (such as by Latour, Woolgar, and Knorr-Cetina, all of whose work he cites) do not provide any evidence that decisions made for non-epistemological reasons “influence . . . knowledge outcomes,” even “local knowledge outcome[s]” (p. 72). He concludes that “among sociologists in general, natural scientists, and the educated public, positivism remains the dominant position . . . it is very unlikely that further studies of the sorts the constructivists have conducted will result in overthrow of positivism in the larger community. It is much more likely that the studies . . . will ultimately cause the larger community to adopt a more sophisticated view of science” (p. 238). Perhaps, then, it is time to give some application to the findings of ethnographies with scientists by using the insights gained into the conduct of science to inform our approach to teaching students. This work highlights that important socially-mediated practices of science are too often ignored in regular science classrooms, or are so formalized that they become rule bound such that they are no longer “social” but instead become inflexible routinized practices.

To address the question, “What do professional biologists do?,” Bill Purves, Professor of Biology and the author of the second best selling introductory college biology textbook, made the following list (Schank, 1993/1994): write technical papers, use and create graphs and tables, test hypotheses by experimentation, formulate hypotheses, extract information from technical papers, make presentations, and identify good research questions. Practicing teachers will immediately note that in most biology classrooms, students hardly ever engage in any of these activities—not to mention the ones further detailed by ethnographies of science. Competence in these practices is built as one participates with others in activities

involving them; viewing knowledge as practice implies that it can be appropriate only by participating (e.g., Bourdieu, 1990; Bourdieu & Wacquant, 1992). A different way of understanding what biologists (scientists) know therefore leads us to different understandings of how we should teach students biology. That is, knowledge of biology/ists cannot be transferred but has to be built up through lived experience, and particularly through participation with others in activities that get the day's job done.

If social mediation, the use of re-presentations such as graphs and tables, and presentation and defence of ideas is necessary to enculturate those who become scientists into being able to interpret scientific claims, then students need to experience similar practices in schools so that they too can develop their understanding of science—whether for becoming someone who themselves “works in science” or to be able to use the findings of scientists as they participate in “everyday” experiences as citizens. The practices of science can be found in many situations apart from the “formal” type of scientific research of which most people think when they think of science—where science is enacted such that research is done, new knowledge claims are made, and research papers are produced. “Informal” science, where the tools, practices and languages of “formal” science are used to achieve ends other than the broad production of ‘new’ knowledge occurs in many other situations. In part, throughout our everyday lives we engage in these practices. For instance, a child playing with a magnifying glass—who first finds out how to burn wood and then determines how different types of wood burn—is engaging in scientific practices. The practices also occur collectively to achieve the goals of a local community group which organizes itself to argue for a new crosswalk where the incident of accidents is high—they use the “tools” of formal science to make their argument, although few would think of themselves as formally “doing” science when making the argument. Groups which engage in community activism to argue against the development of land which is of ecological significance are also using the tools and practices of “formal” science.

Students working in field studies

If “knowledge” is not something which can be transferred into the head but something that must be embodied by participating in disciplinary practices, then the teaching of biology must change. This new view of biological knowledge as practice implies that we need classes where students can actually “do” biology over a long term. Scientists rarely engage in tasks isolated from their broader interests for short periods of time or in continuously changing contexts; but that is exactly what students are usually asked to do. Traditional teaching of science and its practices often engages students in a series of relatively unconnected tasks without any opportunity given to develop their understanding of how scientific arguments and knowledge develop through an accumulation of collected, connected evidence (Roth & Roychoudhury, 1993). If we want students to develop meaningful understandings of scientific principles and the practices of science we need not only to engage them in practices reflecting the work of those in the discipline; we also have to do so over a period of time that allows them to also build a collection of connected claims that give them sufficient resources to make coherent arguments. We envision students to engage in practices which are commonly experienced when doing the “work” of biology—either formal or informal. In that sense, these classes reflect “authentic” practices of science because they allow students to develop their capacity to make linguistic distinctions, acquire standard practices, use ready to hand tools and equipment, and participate in and develop ongoing concerns in ways representative of those found in the ontology of the domain of those doing field work in biology.

As part of our research, we designed and studied innovative ways of teaching biology and its practices to middle school students (Roth 1996a, Roth & Bowen 1993, 1994, 1995; Lee, Roth, & Bowen, 1999; Roth, in press). In these curricula Grade 7 and 8 students developed competencies of doing biological research that matched those of college students (Roth, McGinn, & Bowen, 1998; Bowen & Roth, 1999). In the following section, we

demonstrate, with material from our research, how biology and its practices can be taught as social practice in school settings.

Of considerable importance in our design of science classrooms is consideration of the centrality of rhetorical practices in science (Latour & Woolgar, 1986). Within traditional science classes students rarely use textual means (either spoken or written) to persuade a teacher or somebody else—all too often they are writing not to persuade but to “give” an expected answer (Tobin, 1990; Roth, McRobbie, Lucas, & Boutonné, 1997). On the other hand the rhetorical practices of science often center around inscriptions (e.g., graphs) which were developed (often in parallel with the argument) to support the argument the scientist(s) are making (Latour, 1987). Use of inscriptions, such as graphs, and rhetoric about the meaning of observations are central to the conduct of both science and environmental activism. But, not only is the discourse of students unlike that of scientists and activists in its purpose, more often than not their use of inscriptions is quite different too. Graphs in textbooks that are demonstrating conceptual constructs are often “clean,” lacking in the variations due to measurement error and natural variations that are often found in the writings of scientists in journal articles (Roth, McGinn, & Bowen, 1997a). Participation in rhetorical practices using inscriptions for support is an important aspect of the sense making that scientists engage in, but is often lacking in science classrooms. Thus, in addition to the classroom needing to be an open-inquiry environment to effectively facilitate the learning of and about science and its practices, we maintain that it also needs to be structured so that students define, present, and defend claims that are based on investigations supporting their claims; if necessary, through use of the “authority” of canonical scientific principles. Through engaging in a process such as this students will develop tool-based, experiential resources further enabling their future scientific rhetoric allowing them to make linguistic distinctions commonly found in their area of learning.

Biology as Social Practice in Middle School Science

The structure of the classroom, the activities conducted within it, and the attitude of the teacher involved, are all important features affecting the design of effective biology teaching environments so that students appropriate (although often in a less complex form) aspects of biological knowledge foregrounded in the ontological map. Our conceptualization of such an “authentic” classroom centers around the concept of *open inquiry*. Our research over the past seven years (Roth, 1996b; Roth & Bowen, 1995; Roth, McGinn, Woszczyna, & Boutonné, 1999) has led us to conclude that for such an open-inquiry classroom to be effective it minimally requires five conditions to help students effectively develop the ontological map of biology: (a) problems that are ill-defined characterize the contexts in which students work; (b) the uncertainties and ambiguities of making claims found in science laboratories is experienced by students in their making of claims; (c) the current knowledge state of the students is used to locate the conceptual foundations of the subjects’ beginning; (d) material and discursive practices and resources shared and developed as part of communities of learners; and (e) “newcomers” of the community (often the students) can draw on the expertise of more knowledgeable others or on any other suitable resource that could enhance their learning. Using a framework such as this allows students to develop a different relationship with knowledge than that resulting in traditional science instruction: they will see themselves not merely as the reproducers of cultural knowledge but as producers of personal knowledge (Roth, 1995). In addition, this type of involvement in the practices of science not only influences students’ relationship to knowledge but can also have positive motivational effects (Abrams & Wandersee, 1995).

Developing a “mastery” of science—becoming competent in the practices foregrounded in our ontological map of the biology—is not something that students can acquire by being lectured to or by reading about it but is instead something they must become more experienced in through participation in the component parts of the domain. This is also not,

however, something that students can be expected to acquire on their own or through only interaction with their peers. Given our perspective that students cannot be “told” how to do science, we have re-visited the role of the teacher in our research and have adopted the metaphor of “cognitive apprenticeship” (based on the role played by supervisors of graduate students; e.g. Winston, 1997) to frame our conceptualization of how the role of the teacher in the classroom should be viewed. Rooted in socio-cultural studies of apprenticeship across diverse settings, this framework focuses on the relationships between more and less knowledgeable members of specific communities within which knowledge lies not in the master but within the organization of the community of knowers of which the master is just one part (Lave & Wenger, 1991). Operating within this framework, teachers change from being disseminators of knowledge to being facilitators of student-directed activities with which the teacher acts as a guide asking questions regarding students’ claims that are “unconvincing” and modeling approaches to question asking, problem solving, and defence of claims related to the students’ projects.

In the following two case studies we demonstrate how using the requirement that students construct “convincing” arguments provided a foundation within which they developed many of the practices similar to those found in the investigations of field biologists.

Case 1: Learning biology through engagement in field research

Biology as Everyday Scientific Practice

In a grade 8 science class, students participated in a 10 week session during which they worked in pairs to conduct field research projects on small, five by five meter, plots of land. In that time they proposed and conducted field projects investigating relationships between biotic and abiotic features of the plot in which they were working. To do this they framed problems, collected and summarized data, made various types of inscriptions, and made rhetorical, “convincing” claims about the “meaning” of their findings. They shared

these findings in groups every couple of weeks and discussed differences and similarities between their findings and those of other students (this work, and descriptions of the classroom environment and student work, is presented in greater detail in Roth & Bowen, 1993, 1994, 1995; Roth 1996a). Overall, the students' work showed remarkable congruence with the practices of field biologists; their concerns, decisions, and practices parallel those of the field ecologists in our ethnographic work. Consider the following episode describing one segment of field work conducted independently by one group of two students (Ted and Willy):

Ted and Willy, Grade 8 students engaged in a 10-week investigation of biomes, have staked out a 36-m² plot (ecozone) which constitutes their research site which is located in a wooded area along the creek. Their investigation addresses the research question, 'is there a relationship between the amount of sunlight and plant density?' Ted and Willy know that they have to make a convincing case for their research question, research design, and whatever finding(s) they come up with.

In the field, they decide on subdividing their plot into 36 subplots, which they later combine into 9 sampling areas (consisting of 4 subplots in a square). Figure 3a shows part of the measurements they conducted and field note book recordings on that day. As their notebook shows, they begin their day by deciding on the subdivisions of their research site, and draw a grid in which the number assigned to each plot is recorded. These are the same numbers that then show up in the table where they recorded the number of plants in each of the 1-m² plots.

They also record other aspects including weather (sunny, warm) and an indication of the soil moisture ("ground is wet"), or that there are new plants that had not been there just a few days earlier during their last visit. Later they return to the lab to process their data. In particular, they decide that using a graph will help them best to portray a relationship (Figure 3b).

Based on this graph, they drew the following conclusion.

The information shown on the graph clearly shows that there is a definite pattern, a relationship between sunlight and plant density. There is only one point in our graph that is out of line. That is the area number 7 which is at the top left hand corner of our zone. We found that where there is more shade a lot more plants grow. Usually, horse tails, weeds, snake rhubarb, clovers, and shrubs. By the river bank, there were only a few plants, mostly grass, dandelions, and pussy willows. As you can see on the graph, the number of foot candles per meter greatly increases near the creek because it is not in the shade. We tested this experiment thoroughly and a number of times, so our findings were consistent.

[Insert Figure 3 about here]

In this example there are striking similarities with our observations during the field ethnography among ecologists. Their focus on data tables, and the coordination work to make sure each measurement could be coordinated with all the others (Roth & Bowen, 1998), was typical in the work of our field ecologists. It is also similar to work done by scientists in a remote Brazilian area who investigated whether the forest encroached on the savanna, or vice versa (Latour, 1993). Throughout their work the students demonstrated that their practices are closely aligned with the ontological map of university trained biologists in their use of resources and standardized practices such as representations, collection of background information (e.g., cloud cover), the search for relationships between factors, and use of published information to support their case.

For instance, in constructing their arguments Ted and Willy engaged in a practice common in the practice of science in their use of a graphical representation to support (make more “convincing”) a “case” they attempted to make. Also, their conclusion shows how, because of their familiarity with the site, they could attribute an outlying data point to a particular feature in the field. Like scientists, these students drew on their embodied

understanding as a resource for interpreting their data. (We could show, in our analysis of an extensive data base of scientists reasoning with graphs, that their embodied understandings of the site, the instruments, in addition to the conceptual background of the research allowed them competent reading of graphs, which otherwise was considerably hampered [Roth, Masciotra, & Bowen, 1998]). In studies of graph interpretive practices we found that individuals with field research experience typically identify and exclude outliers from their analysis—it is a common scientific practice. Those who have little practical research experience, even if highly schooled with BSc degrees, rarely identify and discuss the implications of outliers. Further, the latter group, unlike those with research experience, also tend to consider a reported “trend” (either graphically or textually) to represent a strong one-to-one correspondence between the variables whereas those with field research experience tend to consider such reported “trends” to be generalizations around which there is considerable variation. Such differences have considerable importance when it comes to what understanding is drawn from the work of scientists presented in textbooks, magazines, or newspapers which often exclude evidence of data scatter and just show the best-fit line.

In addition to the direct comparisons possible between the work practices of Ted and Willy and practicing scientists, the discourse they used in their presentation and defence of their findings to peers demonstrated that they appropriated discourse elements and made linguistic distinctions in ways similar to those made by practicing scientists in presenting an argument. The competence which these students developed is further underscored by the following. One of the instruments that we had used to evaluate students’ scientific practices was also given to students in a teacher preparation program, all of whom had completed an undergraduate degree with a major in a specific science or in mathematics. While 12 of 17 Grade 8 groups used one or another mathematical practice (graphing, tetrachoric correlation, trend analysis), only 1 of 17 pre-service teachers did so. The other pre-service

teachers found the problem too difficult and did not employ what would be everyday practice to a scientist (Roth, 1996a). These results were confirmed in a follow-up study in which only 6 of 32 preservice teachers (24 with BSc, 8 with MSc degrees predominantly in biology) used more sophisticated graphing and statistical techniques (Roth, McGinn, & Bowen, 1998). Even “priming” preservice secondary science teachers (with BSc degrees) by having them engage in short, correlative research activities in which they were encouraged to represent their findings graphically before they engaged in the interpretive activities did not result in the same detailed interpretive practices as that of the Grade 8 students who engaged in long-term research projects (Bowen & Roth, 1999). Furthermore, while there is a lot of research on the discontinuity of students’ mathematical and scientific practices between classrooms and other (applied) settings, such discontinuities were not observed in the Grade 8 classroom. In part, this is because the Grade 8 students had developed a stock of experiences in real settings allowing them to re-construct new questions or experiences in relation to those real settings. These experiences constitute a base of resources, the tacit knowledge not often apparent in journal articles, that assisted the students in both constructing their own knowledge and in interpreting the work of others.

Case 2: Learning biology through engagement with community concerns

Biology as Everyday (non-scientific) Practice

In three Grade 7 classrooms over two years we framed the biology topics as open-ended investigations conducted as students participated in a broader community project concerning the “health” of the creek draining the local watershed. The design of this unit is based on the idea that science education should be conceived not as a preparation of scientists, but as a preparation for citizenship in which biological concerns are part of the web of daily practices in the community. As part of this community in these classes, students participated with (and as) local citizens working with local environmental groups

who were monitoring and restoring the watershed of a nearby creek—whose bed and course had been greatly altered over the past several decades. These environmental groups, in consultation with government biologists and the support of local political structures, were engaged in: monitoring the organisms present in the creek and their population size, rebuilding riffles, monitoring water flow rates, and assessing impacts of local development. The students were aware of this work and contributed to it. Below we describe the introduction to the unit and the work the students engaged in.

The unit on environment and ecology began with a newspaper article the students in this Grade 7 class read and discussed. Some of the points highlighted and discussed by the students were the environmental problems related to coliform counts. They were concerned how, if, as the article said, beaches were closed due to high coliform counts, it could be fixed, and how much fixing that would cost. The article further suggested that for the long term work the wider community must be involved and suggested that some of the core issues are related to the physical tasks and the wider societal and political issues surrounding the problems and they discussed this as well.

Students considered it as an important and worthwhile task to contribute to the community effort by doing research along Henderson Creek. They began by framing research questions that they could investigate during the following lesson when they could work at different locations along the creek. One group decided they wanted to test for the presence of coliform bacteria at different sites, another group was interested in finding out more about the organisms that live in different parts of the stream and along its banks.

That this was more than just a “school” activity was evidenced by the activities surrounding the work in which the students were engaged. Parents contributed time by participating in driving students to the study sites and many others eagerly participated in the field work by asking students questions, scaffolding methodological approaches, and

helping the students interpret their findings. The regional mayor visited the students as they worked at their field sites and questioned them about their work as did a reporter from the local newspaper. In another aspect of their work, when they were working on a report to present at a public open house, the mayor made himself available to be interviewed and discussed the creek with them and what contributions various groups, including their own class, were making to improving the watershed. Field scientists from this work participated with the students in the field and came and worked with them in their classroom as they worked at making sense of the field samples they had collected.

One day, the entire group conducting research at the Miller Road site (Figure 4; four study sites) decided to check for the relationship between the speed of the water and a number of the different types of organisms they had identified during earlier periods. On Tuesday, they collected data during a double period. First, students collected invertebrate samples from the stream bottom using a Serber Sampler (which has an area of one square foot). To do this they placed the grid on the bottom of the creek with the collecting net flowing downstream and, using their hands, stirred up the creek bottom within the grid breaking up clumps of mud and lightly rubbing the surface of any rocks or debris. Carefully rinsing the sample in the net (to remove mud), they transferred the sample to a small plastic container and marked its collection site. Then, using floating wooden blocks, students collected data to determine the creek speed at the sites at which they had collected organisms in previous weeks. In the team, one student dropped in a wooden block, another kept track of time using a stopwatch, and a third called out when the wooden block had travelled five meters. Each team replicated the speed trials at least three times, and then calculated an average.

[Insert Figure 4 about here]

On the following day, students analyzed their water samples, separating the organisms and using a microscope and pictorial keys to identify them. They counted the number of individuals from each species in their own samples and recorded their results in a large data table drawn on the blackboard (Table in Figure 5).

On the next day, each group examined the entire table for patterns in the class data from which they produced graphical inscriptions. One group produced the graph depicted in Figure 5. The students in that group concluded that there was a relationship between the numbers of amphipods and the creek speed. In discussing their conclusion with the teacher they all made note of the data point which lay well outside of the simple relationship they had drawn a trend line for and the students were introduced, by the teacher, to the term “outlier” which they were told they could use to refer to similar data points. Elaborated by the teacher in the conversation was the possibility that, even though there was probably more oxygen where the stream speed was faster (this had been discussed earlier) something else was affecting the presence of amphipods—which might have included being washed away by the higher speeds, or perhaps the presence of a different predator.

Towards the end of the unit, two groups of 7 students each produced a class poster which they exhibited at a well attended open-house of a local activist group that is lobbying for a preservation of the watershed.

[Insert Figure 5 about here]

Numerous aspects of the practices engaged in by these groups had family resemblance with the work of Sam and her assistants; more importantly, the practices were even more similar to those of local residents also concerned with preserving and improving the Henderson Creek watershed. In fact, their knowledge was at the same level as generated by those local residents as it too was made available to the community itself (Lee & Roth,

1999). Most comparable to Sam's research were the approaches to field research. In both Sam's study and the work of these students (as well as those students in Case 1) new problems emerged as the 'land' was engaged with in the course of trying to "understand" the ecology. In the particular study cited above, students first surveyed where different types of organisms were found, recording the locales on a map that would help them recognize any patterns, and then attempted to explain why there were differing distributions of animals by "measuring the habitat" using the tools they had available. Their field work practices paralleled the field work of Sam who did not do any "habitat measuring" in her first field season and whose measurements, as we showed above, emerged in the second field season as she attempted to explain the distribution of the lizards she was finding. As did Ted and Willy (and Sam herself) these students also used graphs to examine relationships between distributions of organisms and some abiotic factors.

However, there was a substantial difference in the use of the data that was collected in these different projects. Ted, Willy, and Sam conducted their work as an epistemological exercise to better understand the world in which they lived, but without any intended direct "use" of their findings. However, students in the second case study intended to use their findings to better understand a creek/watershed which is of concern to many others in the community within which they reside and to contribute to the discussions made by others about that watershed. In this their research activities lie more in the realm of "informal" science (as it was discussed above).

Conclusions

As a result of the cognitive revolution, knowledge has been conceived in terms of computer and information processing metaphors and was presented as either declarative or procedural (e.g., Anderson, 1985) thereby reducing and essentially ignoring any of the embodied aspects of utilizing that knowledge (see Orr, 1998). Most recently, science educators reconceptualized knowledge into a constructivist framework/metaphor (e.g.,

Wheatley, 1991), but in classrooms it was still the ‘formal’ scientific claims about what was knowledge that students were to re-‘construct’ through their activities in classrooms. Their engagement in so-called “hands-on” classroom activities had the goal that students were to construct the knowledge of others, not knowledge of their own, and teachers struggled with the tension between what their students understood from these activities and what the formal understandings of science were—although the pedagogical approach had shifted, the idea of what it was that constituted the ‘knowledge’ had not. In this paper, and following other efforts in theorizing knowing related to mathematical representations (e.g., Roth & McGinn, 1997, 1998), we proposed a new framework for what it means to know biology and how one becomes a competent practitioner of biology: Rather than conceiving of knowledge in terms of information and conceptions located in the mind, we examined the practices of ecological field work by a professional and students in two different curricular configurations that change the way children think about themselves in the context of biology.

Considering knowledge as something which is embedded in and arises from everyday praxis substantially alters the view of what it looks like when someone (i.e., a student) knows something, which has considerable implications for how pedagogy within classrooms should be approached. By adopting the practice metaphor as a way of understanding and thinking about knowledge, the learning (which itself is a practice) activities shift so that students can enact: (a) talking about and within the subject (asking the questions which address the concerns of science and the rhetorical constructions of claims), (b) using the tools and the standardized practices of science, © experience the (normative) concerns of scientific disciplines, and (d) encounter breakdowns in the unfolding of activities that are typical of science as everyday praxis.

Ethnographic work among scientists also leads to an understanding that doing science is not the rationalist enterprise that many assume it to be; scientists do not follow a clear

step-by-step scientific methodology as they approach their work, but only write about it as if they do. Most scientists appear to acknowledge this, but only in their contingent repertoire (Gilbert & Mulkay, 1984), although some scientists are quite explicit about this reconstructed nature of the process of inquiry in scientific texts (e.g., Suzuki, 1989). Thus, the writing of science articles is a constructed process which underdetermines the activities which researchers actually enact. But, as is clear from our inspection of science textbooks (e.g. Roth, Bowen, & McGinn, 1999), and many studies of science teaching (e.g., Lederman & O'Malley, 1990), this undetermined nature of the writings of science are not taken into account and science is presented as a clearly defined process which reaches irrevocable conclusions. Our observations of and interviews with field biologists reveal that their "facts" *emerge* from tentative beginnings (for instance, measurements made because they can be—not because of planning based on theoretical understandings) and that many measurements develop in the conduct of field research and are not planned a priori. "Science" in classrooms, on the other hand, is presented as a fixed body of facts that has to be acquired (via information transfer) or, with equal symbolic violence to their everyday knowing, re-constructed by students in processes of conceptual change.

What is peculiar about the notion of practice is that it cannot be acquired independent of the context in which it is normally enacted (Bourdieu, 1997). That is, students who listen to lectures are learning, but they are learning how to listen to lectures, not how to enact the practices of science. Therefore, to learn the practices of science, students need to engage in practices similar to or congruent with, but not necessarily the same as, practitioners of science—both formal and informal. In the scenarios presented earlier we saw details of students' enactment of science in two different types of situations. In the first, guided by a teacher with a strong science background, students worked "as scientists." Much of students' evolving practices were constrained to become more scientific because of the condition that they provide a rationale for all steps in their inquiries, and by regular

exchanges with other students to whom they had to defend their claims and what they had done. However, few (elementary) teachers have a science background sufficient to allow them to guide this type of activity. For those teachers, our second scenario, based on a different ideology of what constitutes science in everyday praxis outside scientific laboratories (e.g., Lee & Roth, 1999), offers considerable promise.

In addition, students and teachers from different backgrounds and in different school contexts may find one of these approaches less threatening and more motivating than the other. Another aspect to consider is that most students do not continue to study science after their secondary experience. Our second approach, modeled along the idea of environmental activism or caring for the environmental health of our communities may be more effective at involving students; from early on, they can enact science as involved citizens who use the tools and practices as science for concerns other than generating “science knowledge.” Using this approach engages students in disciplined approaches to making arguments through contributing to a community database and thus fulfills the goal of enacting school “science” in the everyday world of the community. Both of these approaches differ substantially from how science is currently taught. These approaches offer considerable advantages to students in terms of what they learn and how what they learn is part of their everyday life outside of schools.

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In our derivation of the logistic model, we assume that, as N increased, birth rates declined linearly and death rates increased linearly. Now, let's assume that change in birth rate follows a quadratic function (e.g., $b = B_0 + (kb)N - (kc)N^2$), such that the birth and death rates look like the figure. Such a function is biologically realistic if, for example, individuals have trouble finding mates when they are at very low density. Discuss the implication of the birth and death rates in the figure, as regards conservation of such a species. Focus on the birth and death rates at the two intersection points of the lines, and on what happens to population sizes in the zones of population size below, between, and above the intersection points.

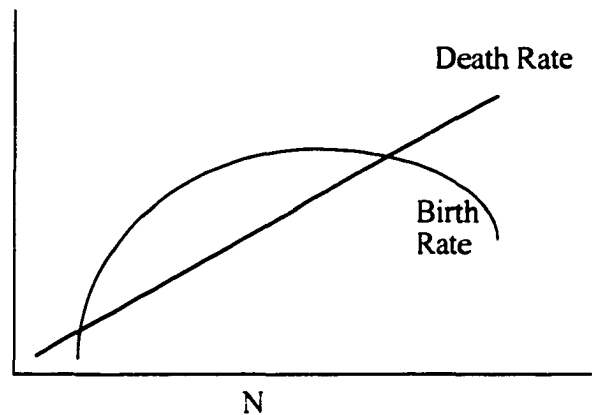


Figure 1. Problem Todd saw on Donna's desk (originally drawn from a similar problem used in a second-year post-secondary ecology course)

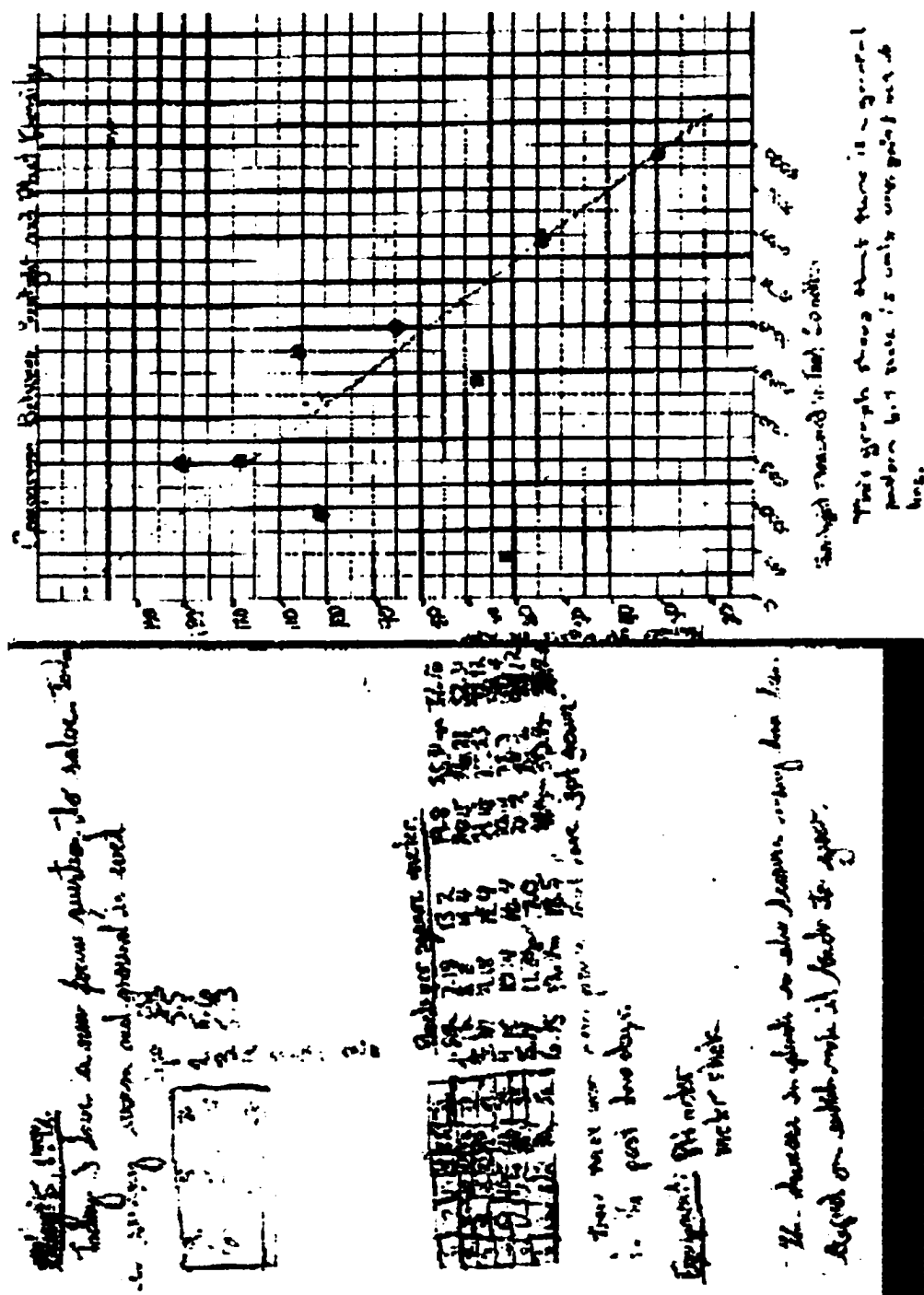


Figure 3. (a) Scan of table from Ted and Willy's field book, (b) Scan of graph from Ted and Willy's field book

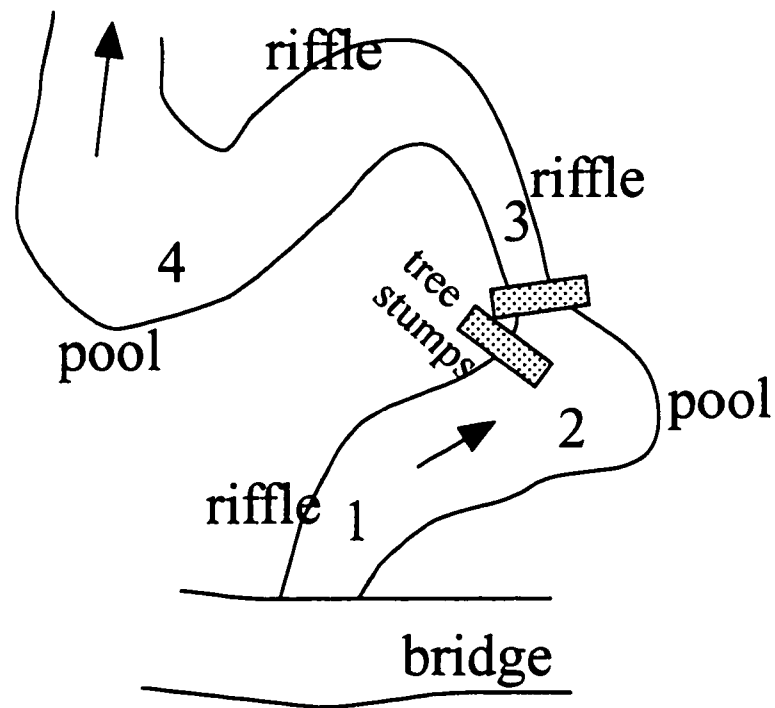


Figure 4. Map of the area at Malcolm Road. The numbers refer to the groups that worked at the different places in the creek, and are the same numbers as in the table. That is, at 1, Bill, Brook, Jen measured 0.11 m/sec of stream speed (last column).

Group	1 SQFT Samples								Speed (cm/s)
	May-fly larva	Caddis fly larva	Crayfish	Planaria	Amphi- pods	Worms	Fly	Damsel fly larva	
1 Bill/Brook/Jen	1	0	x	1	100	0	2	2	11
2 Nicki/Magda/Terr	x	10	x	x	92	x	20	0	18
3 Heat/Leon/Wayne	20	x	1	x	89	x	0	21	20
4 Sh/J/T/Ashley	31	6	0	x	50	0	6	0	12
Site 1 Upstream	1	0	0	0	90	0	2	0	40
Site 2 Downstream	1	0	0	0	30	0	33	0	58

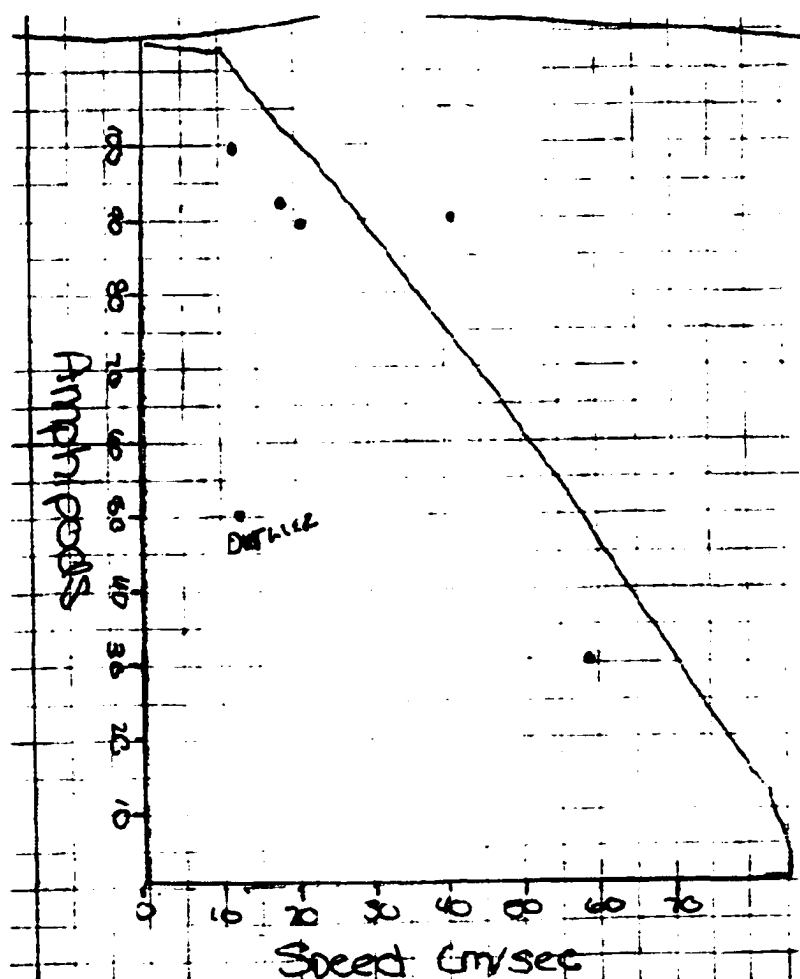


Figure 5. (a) Copy of data table compiled by class, (b) Scan of graph drawn by students to analyze this table.

Chapter 12:

The practice of ecology research:
Insights for science education

The practice of ecology research: Insights for science education

Abstract

In the past several years a number of authors suggested that science education could benefit from insights gained by research in the social studies of science that documents and theorizes science as it is actually done. However, in the past such research was mostly concerned with the practices enacted in male-dominated scientific disciplines including physics and chemistry. Suggestions for the teaching of science drawn from this work reflect these origins, and highlight the paucity of research into the practices of other disciplines such as field ecology. In this paper, we present findings from our own ethnographic work in field ecology. Our research shows that many traditional claims about the nature of scientific research are not consistent with how ecological understandings are actually constructed—and these practices are perhaps more accessible to female students because of how the work and community are constructed. If science educators want to teach science that reflects how it is actually practiced, our work has considerable implications for what science teachers have to do in classrooms.

In recent years, a number of science educators have suggested that science education curricula and research could be enriched by drawing on research findings from studies of scientists and science (e.g., Cunningham & Helms, 1998; Roth & McGinn, 1998b). To provide insights for science education, these papers focused on aspects of the social studies of science including: methods used to investigate the work of scientists, the practices of the scientists themselves, and the effects on learning of considering these issues when designing learning environments. For instance, sociological and anthropological studies of science make use of models and techniques that which are potentially useful to science educators including actor network theory, discourse analysis, ethnomethodology, new literary forms, and reflexivity (cf., Roth & McGinn, 1998a). A better understanding of the characteristics of scientific practice—including its interpretive flexibility, frequent modification of language games, the centrality of inscriptions, and the importance of negotiation—also contributes to a shift in how we view science classrooms, and may provide for greater authenticity and inclusiveness in today's science classrooms (Cunningham & Helms, 1998).

While this recent work on rethinking science education is of considerable importance, it also fell prey to an oversight which it inherited from science studies. Science studies contain a blind spot, for the practices of field science such as ecology is dramatically under-represented (Nutch, 1996). Thus, the nature of science as it emerged from science studies focused almost exclusively on laboratory studies in the 'hard' sciences chemistry and physics. Thus, the model of science adopt by science educators is that of the 'hard' sciences which may not be reflective of other sciences, despite significant disciplinary differences between biology and physics,

Most programs in education research have taken physics as their implicit model for all science without considering the inevitable distortions that result when a research framework is applied to disciplines outside physics. More problematic has been the

tendency for science educators to use the physics model in the development of curriculum to address issues concerning the nature of science, thus perpetuating a misunderstanding of scientific method. (Rudolph & Stewart, 1998)

This would appear to be problematic from a number of perspectives, including aspects of inclusiveness and teaching students about the nature of science (NOS). For instance, the traditional view of science has it that variables are chosen prior to conducting of a study; further, scientific research practices are held to be replicable. Yet, such a view ignores that observational studies and those involving wild animals do not easily fit into this paradigm; observational studies in biology may in fact have more in common with the social sciences than laboratory sciences (Roth, Hall, Bowen, John, & Torralba, 1999). There is some evidence that the various sciences are quite distinct. Yet many portray science more traditionally including the mistaken images “(a) that there is a nature of science to be discovered and taught to students, (b) that a list of tenets can describe the nature of science; and (c) that for a discipline to count as a science, each of these tenets must be true of that discipline” (Eflin, Glennan, & Reisch, 1999, p. 108). Such images are often based on the way physics research is conducted which is also a male-dominated science. It is therefore of some irony that such sciences acts as models for science education. Such mistaken images of what science is like also reign in social studies of science which has traditionally focused on male-dominated disciplines (i.e., physics and chemistry). This is not an issue without consequence. Thus, some science educators concluded that “without considering questions about the nature of science itself. . . it seems unlikely that improving the content of science education will help to attract or retain more women or minorities” (Eisenhart & Finkel, 1998, p. 27). Others suggest that taking laboratory sciences (especially physics) as the model for all sciences partially accounts for the difficulties encountered in the teaching of evolutionary biology and ecology in high schools (Rudolph & Stewart, 1998).

Field research in biology is often viewed as more female friendly. The involvement of women in field research changed the fundamental interpretations of nature in disciplines such as primatology with the work of well-known researchers such as Jane Goodall and Dian Fossey (Haraway, 1989). It is difficult to quantify the changes in gender representation in the field disciplines as these are usually not examined separately from laboratory biology in surveys of graduate schools or employment. But our own ethnographic work among field ecologists on the American and Canadian west coasts suggests that female participation in ecology field research is quite high. For instance, at two recent ecology conferences for graduate students, about half of the presenters were female (72 of 132 and 35 of 70). This approximately represents the university population of ecologists that we have gotten to know through our own participation. It also matches the patterns in another study of field ecologists (Nutch, 1996). This more equitable gender balance in the 'soft' sciences may have occurred for several reasons. First, environmental biology is viewed in opposition to the 'hard' sciences (Eisenhart, 1996). Second, the 'soft' sciences lack the oppressive supervisory and competitive structure found in the 'hard' sciences (cf., Traweek, 1988). Finally, there are tremendous networks of relationships that lead to bonding among members and therefore cohesion within the community of ecologists (Bowen, 1999).

Some authors consider of vital importance that students have first-hand experience in field research to learn both conceptual information and practices of sampling and data collection (Gray, 1982). Not only is there evidence that ecology and its practices are poorly taught in schools, but this subject is also neglected by teachers, curriculum developers, and researchers (Orion & Hofstein, 1994). Even well-intentioned studies intended to better educate students about ecology (e.g., Fernandez-Manzanal, Rodriguez-Barreiro, & Casal-Jimenez, 1999) often present a view of ecology that cannot be confirmed by observing ecologists at work. Given that there are almost no ethnographic studies of how field

ecologists do their day-to-day work, we do not intend to criticize these science educators. To better inform science education, we therefore need more appropriate thick descriptions of scientific practices in ecology that do not underdetermine what scientists of that discipline actually do (Bowen, 1999; Gross, 1996).

The purpose of this paper is to provide a description of typical research practices enacted in field ecology. These descriptions provide evidence of 'authentic' research that goes against the traditional image of science.

Methods: How to Observe Ecologists at Work

Over the past three years we have increasingly relied on our own ethnographic work among scientists as a resource for our science education reform efforts. Doing this work ourselves has come with a number of benefits. First, because of the lack of research on field ecology, our own studies provided the necessary background for implementing innovative curriculum in middle school science. Second, because we did the research ourselves, we can test the extent to which our own descriptions carry across the different contexts. We were able to show in a number of case studies which type of practices are enacted by scientists and grade 7 to grade 8 students (e.g., Roth et al., 1999).

Data Sources

Over the past two years, we conducted ethnographic work among ecologists which included participation in field work, attendance at ten local, national, and international conferences, attendance at talks to interested lay groups, formal structured and informal interviews with nearly 20 ecologists, and participation in informal gatherings. To better understand the field research practices of ecologists, we participated as field assistants in two different field seasons with ecologists from Western Canadian universities as they conducted research projects on lizards, snakes, frogs, and birds in a mountainous area in the midst of southern British Columbia. In total we spent seven weeks as assistants working at this site as we conducted our ethnographic research. Our main informant in this

time was Sam, who collected field data concerning ecology and evolutionary biology of a lizard subspecies, as well as less central informants who worked on projects with other species or who were other assistants working for Sam. As field research assistants we engaged in the daily practices of research, data collection, site maintenance, etc. as directed by Sam at both the field site and the field laboratory (where lizards were housed and other data collected). Data sources from this work included extensive fieldnotes and hundreds of annotated digital photographs. In addition, we conducted formal and/or informal interviews with the various participants involved in studies in the area, collected computer scans and photocopies of paper artifacts (including data records), and made videotape records of pivotal events in the field and field laboratory.

This fieldwork was contextualized in our analysis by field notes recorded as we later attended symposia/conferences with the graduate students engaged in this field research, socially interacted with informants at least once a week in informal settings upon return to the home university, visited various members of the community in their laboratory settings at the universities, observed and had discussions with members who were working as teaching assistants for various biology courses at their home universities, and conducted interviews with ecologists on their field practices. In addition, extensive (ten hours) videotaped interviews with Sam were conducted between the two field seasons regarding her research practices and subsequent analyses.

To increase reflexivity of the research, we opted for a particular style of ethnography in which one investigator works on site (Bowen) and the other acted as a reflective partner from the distance (Roth). Using email, we interacted extensively on a daily basis. Daily, Bowen sent materials such as field notes, photographs, and transcriptions (of video and audio materials); Roth returned more theoretically-oriented reflections and comments or requests for further data collection. Interacting like this forces the 'part native' on site to make explicit any of his tacit assumptions. This distribution of roles also embodied a

particular form of Ricœur's (1991) hermeneutic phenomenology which draws on the complementarity of explanation derived from critical structural analysis and understanding derived from lived experience.

Analysis of Data

Analysis of the data of the ethnographic data examining field practices was conducted in both an on-going fashion and at the conclusion of the study. On-going analysis of the field data was conducted to help establish the "credibility" desired in the conduct of ethnographic or qualitative research—a parallel to internal validity (Guba & Lincoln, 1989). Two of the criteria for establishing credibility are peer debriefing and member checking and these both occurred as a consequence of the ongoing analysis of data as the study progressed. During the study, active analysis of the field data was shared between the authors so that interpretations and observations could be critiqued and further questions asked. In addition, analyses could then be checked with the member ecologists or un/substantiated with further observations. To aid this, field interviews were transcribed in an ongoing fashion and contributed to the analysis of the field observations.

Our first set of analyses were checked with our main informant after the first field season we had spent with her. During ten hours of video taped interviews, we followed up our tentative hypotheses about ecology as a field science. During these interviews, we also used graphs and other formal mathematical representations to find out more about Sam's understanding of research methodology. Finally, we used these interviews as an occasion to find out more about Sam's plans for the subsequent field season during which we participated again. In this way, we gained an understanding of the extent to which the research emerged in the field versus how much of it could be and was pre-planned. (For an extensive sociological study regarding our findings see Roth and Bowen 1999)

At the conclusion of the data collection (which spanned over two years), analysis of all resources (video- or audio-tapes, transcriptions, written field notes, photographs,

published papers, copies of conference papers) was first conducted individually and further tentative assertions made and then checked against the data set. In this analysis, we subjected all texts to an interpretive text analysis grounded in discourse analysis, (Potter & Wetherell, 1987), semiotics (Bastide, 1990), and hermeneutics (Guba & Lincoln, 1989) of scientific texts. Collaborative data analysis then followed as we convened in joint sessions (with other members of our research group) to compare and critique our independently arrived at interpretations. When members agreed upon an interpretation, the entire database was then reviewed for evidence which substantiated or did not substantiate our taken-as-shared interpretation. Several such sessions in which we progressively focused our claims resulted in the information reported in this paper.

The Nature of Ecologists' Research Practices

Two major areas of the research practices of ecologists warrant mention—those related to issues of actually conducting their research and those related to narrative exchanges important to constructing social aspects of their community. These two areas are not unrelated to each other, but are separated in our text to best allow a thorough discussion of each. To support claims we present examples found in our field notes, interviews, discussions, or presentations by ecologists.

Emergence of Field Practices

Science, particularly in its formal writings in journal articles, is presented in a rationalistic way. In the past, philosophers and sociologists of science used this as evidence for the claim that scientific research is conducted in a planned, linear fashion. In science education, this led to many teaching and curriculum practices that emphasize a similar linear form. In part, this linear form provides authority to the text such that the knowledge claims and methodologies are beyond question. Our observations of field ecologists while they conducted and discussed their day-to-day work suggests that the formal texts of ecology do not adequately represent how field research is conducted. We noted several major practices

of field ecologists which differ from laboratory sciences, especially those which are experimental.

Ecological field studies examine interactions that occur between different components of highly complex natural systems. As a result, ecology is more an observational than an experimental science. In part, this can be ascribed to the fact that ecological systems resist the reduction to a small number of factors necessitated in experimental research. This resistance arises from the difficulty of resituating experimental findings in complex systems. That is, experiments with small number of variables are seldom generalizable to natural settings and thereby negate the utility of the experimental results. (In this, ecology is not unlike education where laboratory studies conducted by educational psychologists rarely scale up into natural settings.) In addition, the results of field studies are highly contingent: the local circumstances mediate research design to such an extent that the techniques and approaches useful in one setting may be inappropriate in another. This contingency means that ecologists can rely less on standardized practices than laboratory scientists who frequently follow strict protocols (the model for school science laboratory activities). This has several consequences for the conduct of ecology research. In the following, we discuss four salient properties of ecological field research that differ from the traditional image of scientific process. Research design in ecology has an emergent character, tools are highly context-specific, the most important variables often emerge *after* the research has started, and studies are not easily replicable because of the dynamic nature of ecological systems.

Emergent Nature of Research

Ecological field research is highly locally contingent. This often means that studies must be designed for each setting, and this design only emerges from the activities as researchers spend long periods of time making extensive observations of their setting. For this reason, graduate students are expected to work several years in the field. Masters-level

students usually spend two seasons, Ph.D. students three or four seasons, in the field before they can aspire to writing their theses. As a researcher engages in prolonged observations, various features and interactions within their field setting become more salient to them, and from this they then begin to ask specific questions (or identify variables) about which they begin to record data. In this, mature researchers in the field differ little from the Grade 8 students in one of our projects who, as they became increasingly familiar with their research, conducted projects with up to three dependent and three independent variables simultaneously (Roth & Bowen, 1994). Lack of familiarity with a setting (not unlike that experienced by students when facing a new project) require prolonged periods of observation so that salient dimensions can be identified. For example, an ecologist—known for his research on salmon and forest in the Pacific North-West who had already spent some 20 years in the area—describes the emergence of variables for a new project after he spent several days just walking around. During these days he simply observed the biodiversity in one estuary and stream:

Looking at sort of all utilizers of salmon, all the species that utilize salmon, and the consequences of how these salmon are used and what this means actually for forest biodiversity. And this was one of the unexpected, serendipitous observations that came from this initial interest—we began to focus on bears because they were one of the major consumers of salmon. We actually looked for bears in the daytime and they're not present in the estuary at all. From seven o'clock through to about three to four o'clock in the afternoon, no bear is ever on the estuary despite the prevalence and abundance of salmon everywhere in the estuary. Come twilight, rustle, rustle out of the forest comes the first bear, and five minutes after night you have the maximum number of bears feeding and throughout the night these bears are capturing salmon.

Even as he becomes familiar with the estuary and stream, new research questions emerge and with it, new research designs that focuses the ecologist's observations and permits new variables to emerge. Sometimes ecologists enter the field with a general questions. Thus, before Sam went into the field, she asked "What is the natural history of a species of lizard?" However, as we served as field assistants, we observed many variables become salient that had not been pre-determined. Thus, only after she had been at her research site for some time did Sam note lizard color as something to be measured. Only in her second year did she attend to the distance between a capture site and the nearest rock pile. Also, the effect of time in captivity and type of housing became salient only during the intermittent period between year one and two of her study.

In another instance well documented in our data base, the salmon and forest researcher in the Pacific North-West, the focus of research became the bear-salmon interactions as a consequence of observing how often bears predated salmon. Originally, he had attended to neither species but had a long standing, two-decade old research on some stickleback species. However, the new interest sparked by incidental observations led to extended observations on the bear. From these observations, he began to formulate a new research agenda during which specific variables emerged again over the course of several years of explicitly focusing on the salmon-bear interactions. This is illustrated in the following excerpt:

If it's a male [salmon], it takes the brain and the back, but one tissue that the bear will not feed on, that the bear will **not** feed on, are the testes. And what you find when you walk through the forest, are testes strewn around every tree. Bears, for whatever reason, do not like testes. What a nice bonus that is for a biologist. You can pick up these white sacs, and think there's got to be some information there, but, is this sac half full? Is it 3/4 full? How do we figure this out? Well, we can go down to the estuary and all those salmon that got stranded and were dead, we cut

them open. These were all pre-spawned, and here's a male with a great giant sac of testes, 3.1% of the bodyweight. So we can also go into the river and look at the bottom of these pools where spawned out salmon accumulate, these sort of rotten carcasses. We can cut them open and here's this little sac, this empty sac. This is spawned out. This is 1.1% of the body weight. So out here in the forest where the bears only left us a bit of the jaw, the odd bit of muscle tissue, and the testes. What do we do? Well, we can weigh the testes. We can then figure out the pre-spawned testes weight. We now measure the jaw, we then look at our conversion of what that salmon originally weighed, and then we can determine the portion of testes that remain.

The researcher did not begin this study with a focus on bears or expect bears to carry salmon into the woods, to find "testes strewn around," or to stumble upon salmon jaws left behind. As this ecologist spent time observing the artifacts left behind by the bear, he developed data which could be correlated and thereby construct new knowledge about the natural conversion of biotic energy sources (salmon) by complex chains of interacting events and organisms. He became so interested that he decided to develop this into a new research project.

In both examples, the lizard and salmon-bear projects, important aspects of the research—specific variables—emerged from tentative observations and became increasingly salient with the familiarity of the researchers as they spent years in their ecosystems. This emergent aspect of field work makes it necessary that researchers learn to adapt their day-to-day plans to local and temporal contingencies. That is, ecologists have to be flexible to deal with the particulars of their setting including the unfolding climatic conditions that mediate what they can do at any single day or season. One of our informants spent an entire summer in an area that was turned into a swamp by constant rains mediating what data he could collect. Individuals who found themselves unable to deal with these constantly

changing conditions were considerably stressed and sometimes abandoned a project and even their graduate work. Being flexible and being able to adapt research plans to changing situations (such as weather) is a necessary skill for a successful field biologist.

Tools are Highly Context-Specific

Based on our observations of field ecologists we arrived at the conclusion that tool use is complicated by unexpected and unpredictable conditions in which researchers might find themselves. This often means that field ecologists need to adapt local resources for their research purposes. For instance, our lizard ecologist Sam noted in the course of her project substantial differences in skin color of her animals. She had the hunch that skin color may mediate the interactions with other lizards and predation (more visible lizards are less likely to survive). She decided to determine (perhaps even measure) skin color so that she could gain additional insights. In the remoteness of her research site, she attempted to collect some initial information with the resources at hand in a small nearby town. This meant that her ability to obtain tools were limited both by budget and her location so that she tried to *make do* (Harper, 1987) with those resources actually available. In the following field note, we captured her effort in quantifying the skin color of lizards which she wanted to monitor over time:

She first tried taking pictures, then shifted to “paint chips” (i.e., strips of paint color for color matching in homes) from the local hardware store. However, the pictures were unreliable from day to day, and the paint chips did not have sufficiently subtle variations to label lizard color accurate enough. In addition, she felt labeling lizards as “forest tan” or “sand” inappropriate for a “scientific” research project. When she shifted to using Munsell soil charts during the following year, she took the idea from a paper that looked at changes in color in the throat of a chameleon. However, the range in color categories used by the authors in the article were considerable, but in her lizards the color difference was tiny. She needed the finest determination

possible so that she wanted to work with the numbers. She talked her supervisor into buying Munsell soil charts that allowed her to quantify lizard color.

In this case, we see how tool use changed in the course of the investigation. The Munsell soil charts came into play only during the subsequent year and only after she stumbled over another piece of research that had made use of this tool. Munsell soil charts are standardized colors which give quantify hue, value, and chroma of each color. This demonstrates that tools are used as necessary to accomplish a task—in this case, a color scale intended for using with soil was adapted to use with lizards. However, even this standardized tool did not immediately lead to a standardized practice. Repeated attempts to make color determination consistent (using both within and across rater reliability) showed a great variability in the assessments. Similar to the difficulties in other research projects, standard tools do not necessarily lead to standard practices (e.g., Jordan & Lynch, 1993) so that researchers have to work with others who are already experts at using the tool. However, in her isolated camp Sam did not have this option. If she wanted to get anything done, she had to find in her own activity a way that reliably assessed color. In her effort, Sam did not need to meet some arbitrary or external protocols or standardized practices, but instead needed to be able to convince others that her practices made the most sense in the context where she worked:

Sam then set-up for doing the color analysis of the lizards. Color analysis takes place in a box placed sideways with a clip-on lamp designed to maintain consistent light for day-to-day consistency and the Munsell chart standards are placed in the box. Sam brought over her first lizard and asked Stephanie to record the numbers. Sam first called out a number representing the percent black, and then laboriously examined the lizard against the color standards. She moved the lizard back and forth from hole to hole in the Munsell chart, and switched cards three or four times until she finally announced numbers representing hue, value, and then chroma based on

the closest color match to the lizard. She recorded the temperature of the room within a few minutes of measuring the lizard and again some time later (about 1/2 an hour) after recording the color. Sam was concerned that the skin color was affected by dirt and dust so that, after doing a number of lizards, she began wiping them before the actual determination. But then, she noticed that the lizard was about to shed, and decided to keep track of shedding schedules to see if that was related to basking behavior and the color. Yet another variable has emerged.

This excerpt offers further examples of the emergence of variables as further observations were made as the research unfolds. In developing practices related to color measurement, Sam was constantly aware that she would have to justify her decisions to both peers and more seasoned field researchers. She therefore spent considerable time attempting to make her methodological approaches as well-grounded and seen-to-be-sensible as possible though it was also clear from our observations that audits are never conducted because they are too labor intensive and time consuming. Yet in her effort to accountably determine color emerged her new concerns about temperature and shedding because of their possible effect on color.

Significant Variables often Emerge from the Research

During our work among field ecologists, it became increasingly clear that their field practices were little driven by theoretical discourses in the field of ecology (see also Roth & Bowen, 1999). The measurements they made were less driven by local or global theories and more because it was possible to make them. Thus, lizard tail length, arm length, leg length, and body length were measured first because they were measurable. They developed increased significance only later when Sam found that they were reliably correlated with other factors as shown in her statistical analyses conducted during the winter after the second field season.

Sam in the field laboratory, timing lizards as she chases them along a race track

‘I don’t know if I will be able to use these speed measures, but I do it anyway.

Maybe there is something, maybe not.’

Sam presenting the results of her work in a colloquium: ‘And it turns out the longer the lizards are kept in the lab, the slower they run. Which is kind of interesting, but I can statistically control for this effect and go on to look to see if there are other things that are important. And it turns out there are. One of the things that’s important is what sex you are. Adult males are typically shorter than adult females, uh, their body lengths are shorter. And adult males also have relatively longer back legs than adult females. And it turns out that this body length and back leg length is important for predicting how fast it runs.’

Thus, variables gained their (new) significance as correlations between measures which were originally conducted for different purposes are brought together analytically. Sometimes, such a new variable emerged during statistical analysis when the expectations about correlations were not met. For example, Sam pursued the hunch that leg length and sprint speed are correlated. However, her initial statistical analysis did not support this hypothesis. Then, and based on remembering a single observation of a female lizard being particularly slow after five days in captivity, Sam decided to run the analysis again, this time controlling for time in captivity. Lo and behold, the sought for correlation became statistically significant. In this way, a record that she had kept only incidentally—the days of capture and measuring sprint speed—allowed her to calculate days in captivity which then became another salient variable. Although this variable did not exist while we were in the field camp, it was certainly salient during the presentation Sam later gave and from which the above excerpt was taken.

Ecologists engage in exploring data in a manner that allows them to find relations between variables which they had not previously considered to be of any importance to

each other. From such a statistical study, Sam concluded that body and leg length were significantly related to the speed at which a lizard could run. Furthermore, in their analyses data “outliers” also provide ecologists with information which affects their analysis and interpretations. Our field notes describe how an accident in the laboratory, which resulted in a lizard becoming an outlier (i.e., a notably distinctive individual) in Sam’s data set, resulted in her further investigating what she concluded was a significant relationship:

Sam was in a buoyant mood because she had finally found a strong statistical relationship between the factors she had measured “and what determined litter size.” She said that the key was the female lizard that she accidentally tore the tail from “the more you invest in your tail, the less you invest in your kids.”

This and the previous examples illustrate that analytic approaches in ecology are also emergent, unlike the hypothesis testing of experimental results promoted in laboratory studies. It is important to note that these emergent practices are strongly contraindicated in the writings of ecologists. For instance, in journal articles one might be led to believe that variables were decided before engaging with the field setting and that analytic methods were pre-determined. Our observations suggest that this is a stylized construction intended to lend authority to the eventual claims made from those studies. Similarly, our observations of field ecologists while teaching university classes show that they maintain the classical image of a science. This image was portrayed in the classes by the same people whom we knew from their research contexts; that is, we observed a stark contrast between how ecologists conducted their research and the way they presented it in their formal texts and in their lectures to future biologists.

Ecological Studies are not Replicable in a Strong Sense

Science is often presented as only being able to draw claims from studies that are replicable. Yet, such is not possible in ecology research for several reasons. First, local environmental conditions, although they may be similar from year to year are never “the

same” and thus any studies conducted in later years may or may not come close to the claims of the original studies. Secondly, studies of ecology often involve data collected from individual organisms and thus variation in the population (behaviorally, genetically, etc.) might result in differences. Even in situations in which the same individuals are available (such as in studies where all members of a population are known and identifiable) those individuals change from year to year due to aging and changes in the local context (predator numbers, food availability, etc.). This changes the organism-environment unit which, according to many biologists, is irreducible (e.g., von Uexküll, 1928) so that even research with individual organism is therefore not replicable in a strong sense. Finally, the emergent nature of ecological studies also undermines the concept of replication. For instance, in the study with lizards Sam was concerned that the size of her enclosures in the first year of her work dramatically affected the stillborn rate of her pregnant females. Sam therefore altered the enclosures in the second year. Thus, in some aspects it was not possible for her to compare her findings from the first year from those in second and third (although she could statistically control for some of these differences). As another example, the earlier mentioned ecologist who spent a summer in a waterlogged area found entirely different, drier conditions during his second year. Thus, though the site and researcher can be considered under some aspects as “the same,” the organism-environment units he studied were not the same at all.

Published journal articles are also of little help here because they detail only surface aspects of the conduct of field work (see Bowen, 1999) and therefore even if the other problems related to replication did not exist, the methodology sections of journal articles are insufficiently detailed to follow prescriptively to replicate field research. At best we are forced to the conclusion that “In contemporary reports the possibility [of replication] has replaced the fact of replication” (Gross, 1996, p. 87). It generally appears a stronger statement than that to which much of ecology research could aspire.

Interactions foster a Sense of Community

Anecdotal stories shared amongst ecologists are an important way in which they develop their insights into ecological situations. For ecologists, “anecdotes” are important observations, insights, or experiences they have had that nevertheless do not fit the structure of scientific writings (whether stylistically or for reasons of insufficient data) that they nevertheless feel are important enough to warrant communication to other ecologists. The following fieldnote excerpts detail how a conversation in an informal setting (over lunch) between two ecologists who work on different organisms provided each further insights into their own work:

Ecologist 1: Described how he could wade into the stream and literally “pet” the fish which hardly moved. He said this was quite different from how they behaved in the daytime where they would impossible to approach and reacted to any shadows or movement near them. He speculated that this might have something to do with the seals. At night, water is slightly phosphorescent and movement of the fish would lead to them showing a glowing outline, possibly visible to the seals waiting for the salmon in the mouth of the estuary. It would therefore be better for salmon to move as little as possible at night (in evolutionary terms, they would likely be selected for not moving at night).

Ecologist 2: The ecologist told a story about radio-tracking porpoises and not being able to figure out why they logged [seemed not to move] at the surface at night time until they had one in captivity in a large salmon net and watched him doing the same thing. When he moved his outline was quite noticeable and sharks which are a major predator of porpoises might have cued in on this.

These anecdotes describe field observations and interpretations of them that provided insights into predator-prey relationships; but were not the sort of thing reported in a journal articles. However, these individual field observations and interpretations gained more

significance when combined and contributed to the broader ecological understandings amongst the ecologists socializing in that group.

Our observations suggest that ecologists spend a considerable amount of time socializing with each other, and that often the socialization involves discussion not of knowledge claims, such as found in journal articles, but of their own diverse practices and observations. It is in this manner that ecologists develop a repertoire of methodological approaches to use in the field settings and learn to focus their attention on different aspects of the settings they are studying. Thus, for ecologists, narrative exchanges, particularly in informal settings, compensate for the manner in which formal writings are required to be styled for publication.

Sharing of heroic stories as part of these narrative exchanges also contributes to the social construction of the communities of ecologists. These are not heroic stories in the classic sense they are used in science education (See Milne, 1998) but are rather usually tales of personal experiences rather than stories of the accomplishments of others. Although these heroic stories may relate dangerous situations or deprivation, they may also be presented as descriptions of adaptation of research plans to unforeseen challenges or other such accomplishments. Stories which relate tales of the field often are presented in an allegorical fashion so as to offer the listeners guidance as to what practices should or should not be used when conducting field research. The following excerpt from a conversation between two ecologists relates a heroic story:

Mandy: I slipped off a log when marking a trail with orange tape and fell onto my ribs across another log and fought for consciousness and then passed out. I awoke 15 minutes later with my face buried in the moss, draped over a log [described this very dramatically] almost unable to breathe or move. I painfully made my way out of the woods, which thankfully I was only into 100m, to my truck and then drove to my camp. It took my camp partner three hours to drive me to the hospital over

the logging roads with every bump causing me to stop breathing because of the pain and they kept me off work for ten days.'

After she concluded her story, the other ecologist asked if she had spikes on her boots, to which she replied no. The other ecologist berated her for that and for not having other safety equipment with her so that after she had passed out she would be able to call for help if she was unable to make it to the road on her own. The other ecologist then related his own tale of survival working in the woods.

It is through the sharing of common experiences such as these, and the relation of stories about diverse field observations which complement each other, that field ecologists constitute their community and establish who is a member in that community. The type of "shop talk" found in laboratory settings (Lynch, 1985)—the discussion of work practices and interpretations as it is occurring—happens much less often in ecology because ecologists spend a substantial amount of their time working in settings far away from their home university and other ecologists. Thus, social interactions between ecologists in informal settings is an important component of the successfully doing field work—in many ways as important as the formal writings of the discipline.

Conclusion

We have identified and discussed several properties of ecological field research that differ from the traditional image of scientific research. In general, the design of research in ecology has an emergent character, tool use is highly context-specific and often involves adapting what tools are at-hand, the most important variables to explain natural phenomena often emerge *after* the research has started from either increased familiarity with field settings or during analysis, and studies are not easily replicable because of the dynamic nature of ecological systems and what phenomena within them interest ecologists. In addition, narrative exchanges are quite important to constructing social aspects of the community of practice of ecology.

The details of the practices of ecology research related above present a science that is different from the hegemonic descriptions of typical Western science in ways which may offer particular advantages to females interested in science (which may well explain the high proportion of women working in the discipline). Beneficial outcomes in studies of science for young women have been described when their research projects were structured to offer the opportunity to be creative and alter research approaches as studies progressed and to investigate issues about which they were concerned (e.g., Richmond et al, 1998). The practices of these young women in many ways paralleled those of ecology researchers who we observed in our ethnographic work, especially with regards to the creativity and individuality of the projects. For us, this is what represents science—opportunities for creativity and individuality—although perhaps a science that lies in opposition to the laboratory and physics-based constructions of science used in science education.

Better understanding the practices of ecologists also provides more flexibility for teachers that want to engage their students in practices that fall outside of the typical conceptions of science practices by providing them a model of science which is based on emergent designs and variables, the development of tools (which are scientific because of their use, not their original design), and the importance of communities that spend considerable time sharing practices and stories about their research. In essence, by being able to draw on examples of ecologists teachers are better able to present these practices as valid science.⁹⁸ If apprenticeship models in science education, such as some researchers have called for (e.g., Brown, Collins, & Duguid, 1989; Richmond, 1998; Roth & Bowen, 1995) are to be successful we have to better understand the scientific practices of all disciplines of science for the design of those programs. We cannot model all science

⁹⁸ Such a proposition may sound trite, but in our own work as teachers we have both encountered opposition from parents and administrators who did not accept that engaging in practices such as this actually constituted “science.” By illustrating that scientists such as ecologists actually engage in practices of this sort we hope to have provided teachers some material for rhetorically engaging with objections of this sort.

teaching on a few laboratory sciences (especially physics) and continue to believe that we are offering a science for all. Understanding the practices of ecologists is an important step to elaborating the practices found in field-based research which have been long ignored in our classroom curricula.

Implications for Education

Teachers do not just act as knowledge resources, but also as validators as to what is acceptable knowledge. However in ecology, and science in general, there is no single arbiter of what knowledge claims are acceptable. Sam felt herself accountable in her practices first to her peers and supervisor, and then to her broader community. We can understand such a community as a community of validators in which members develop a taken-as-shared view of interpretations and knowledge claims (Cobb & Bauersfeld, 1995). Students, however, experience decisions about correctness of data in ways which do not capture this type of community, instead either relying on external authorities (such as the teacher), acceptance of all ideas, or democratic majority votes (Vellom & Anderson, 1999). For teachers to view knowledge in a manner in which they are less central requires them to relinquish some control and authority, but this would help students develop more realistic conceptions of knowledge and science.

The context of field ecology research differs from many other sciences because it involves settings about which the participants have little embodied knowledge. The knowledge resources found in laboratory settings (such as experienced researchers, detailed written resources, and considerable equipment) are often absent, and communication between the field setting and those knowledge resources is difficult. In many ways this resembles the settings in which teachers, especially middle-school teachers, find themselves teaching—for the settings in which they teach often lack science subject matter specialists and adequate science equipment or textual resources. The remote settings in which ecologists conduct their work explains, in part, why they interact socially

to such an extent: They need to rely on the knowledge of their peers as a resource for conducting their work. In school settings providing students space (both time and physically) to discuss their research practices, such as ecologists do, would allow them the opportunity to rely on knowledge other than that gained from the two traditional knowledge resources in the classroom, the teacher and textbook. Providing students with opportunities to work on research projects which differed within and between classrooms would allow them to develop a repertoire of experiences which would foster conversations which dealt with their projects. It is not much of a leap to consider that the reason so-called off-topic conversations occur is because students have not experienced science classroom activities different from those of other students which they could use as a focus for conversation. By having all students work on the same projects we have removed the opportunity for them to develop a social community around their scientific practices and investigations such as that found amongst ecologists.

In ecology even experienced researchers spend time observing their research settings before focusing on the specific questions they are going to address. In schools however, students are often given little time to gain any observational experiences of phenomena before they develop research questions, and all too often what questions they are to address are provided to them. Yet, prolonged observation might well lead them to recognize that variables are developed from both disciplinary and personal interests, not that they exist transcendently 'in the ether' without human influence. We have shown exactly such benefits even when students work only over a period of 10 weeks in the same forest developing research questions from their own interest and only under the constraint that these questions and the research has to be convincing as judged by their peers (Roth & Bowen, 1995). Similar benefits would arise from allowing students to develop their own questions, their own variables, and their own interpretations. In this type of setting, teachers would act more as facilitators of practices than as instructors. Teachers working

with students in a type of “cognitive apprenticeship” offers considerable advantages for the knowledge gains made by the students.

In particular, developing in students an understanding of how scientific claims are developed by engaging them in activities such as we observed ecologists engage would help them understand that such claims are not irrefutable and “provable beyond a doubt using empirical data alone.” This is especially important given that they may one day be responsible for communicating the ideas of science to others (Ryder, Leach & Driver, 1999). Students seem to expect that the primary way in which consensus is reached in science is through experiments that provide unambiguous answers (Larochelle & Désautels, 1991; Ryan & Aikenhead, 1992). This makes it more difficult to (successfully) teach science disciplines whose data often contains substantial variation including animal behavior, ecology, and evolutionary biology (Rudolph & Stewart, 1998). Engaging in ecology research projects would provide students the opportunity to learn that unambiguous relationships are uncommon in many scientific settings. Students would gain if they came to understand the limitations of scientific claims, especially the variability in data that often underlies even the strongest of scientific claims in biology. Such work by students would also help them to better develop their understanding of scientific theories, since many scholars maintain that understanding scientific theories, inscriptions and claims cannot be separated from the context of their production and use.

Studies of classrooms which have been structured to encourage students to develop a microculture similar/congruent with that found in scientific communities are not very common (e.g., Roth, 1998; Vellom & Anderson, 1999). However the few existing studies suggest that students are capable of developing rhetorical practices and problem-generating and solving practices demonstrating the generation of scientific knowledge quite different from the re-presentation of the authoritative claims of teachers or textbooks. These studies also make clear that such approaches are time consuming compared to the so-called

efficiencies of regular curricular approaches but argue that the outcomes, especially with regards to implicit and explicit understanding of scientific endeavors—and thus what we would call scientific literacy—outweigh that cost.

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Chapter 13:

Implications of studies of ecologists
for teaching and teacher education

In the papers that constitute this dissertation I examined the practices of ecology, particularly how newcomers learn these practices and what they learn about them. In so doing, the papers extend our understanding of ecology as a discipline from both an educational and a sociological perspective. Given that teachers and public schools are now expected to teach their students about “authentic” science, understanding the everyday practices of scientists becomes that much more important—both so that students have a better opportunity to learn those practices as well as providing the academic community the information necessary to allow a more reflective stance on the nature of these practices. Many studies of laboratory and physical scientists and their practices have been conducted, but little work has been done to examine the practices of field biologists. By providing insights into the practices of field science the research discussed here offers educators a different model upon which to base students learning, for field science is different than the laboratory science about which most people are familiar (and from which they have developed a sense of what science in general is). I do not want to just make the broad statement that students should learn “authentic” science. Rather, better understanding the practices of scientists allows educators to ask whether we want students and student teachers to develop the same worldview as ecologists. Alternatively, it allows educators to ask whether we want students to develop an understanding of ecology which includes a reflective critique of their worldview.

As a collection, the papers in this dissertation suggest that undergraduate education in science poorly serves students in science, especially those entering disciplines involving field research, if the goal is to make them competent practitioners of science. More importantly, these programs do not well prepare individuals to become teachers who can themselves enact the scientific practices which are congruent with the everyday practices of scientists encapsulated in the phrase “authentic science” called for in various reform documents. This claim is founded on the results reported in the various chapters which I

will now summarize by broadly drawing together the conclusions reached in and across the different studies. Overall, the papers in this dissertation provide insight both into how we can better prepare teachers to teach science as well as what activities make most sense for students to participate in to learn about science.

Summary of Findings

Overall, several of the studies suggest that individuals without research experience engage in different interpretive practices (especially of graphs and data) than do those with research experience and this leads to different understandings being reached about what those inscriptions mean. Given that the inscriptions are linked to conceptual claims, it is clear that difficulties with the interpretation of inscriptions could result in understanding concepts and knowledge claims in a way other than that intended by their original authors.

A major difference between those with research experience and those without was that the former draw on real world examples and personal experiences to make sense of graphs, the latter rarely do so. Even if there are aspects of their everyday existence which might inform the interpretations of non-researchers (such as the relationship between light and plants, or plant distribution changes with altitude), these were rarely used to help interpret inscriptions. This suggests that the practice not yet acquired by those with undergraduate science degrees (and others) is the general one of drawing on personal experience to make sense of inscriptions. When interpreting their own graphs, experienced researchers generally did not discuss the graphs directly at all, but instead embedded their discussion in a rich, detailed, description of their research setting—notably different from how preservice high school teachers discussed their graphs in their own reports.

When interpreting graphs participants without research experience also did not distinguish between empirical data and models—which may well have occurred because lectures and textbooks rarely distinguish between them either. Graphs in textbooks and lectures also did not show any data scatter but instead usually showed the lines of best fit

without any of the raw data. This presentation suggests that the relationship between variables was unambiguous—although this clearly was not the case in the inscriptions found in journal articles. In part, this explains the interpretative difficulty many participants had, for they often did not make claims of relationships when there was any data scatter, unlike the claims made by those who had used graphs in summarizing their own research in the past. Lectures contributed to student difficulty with interpreting graphs in yet another way. By virtue of their structure, lectures do not provide students any experiential resources on which to draw to make sense of the information encoded in the graph, and it is these experiential resources which experienced researchers made evident were central to interpreting graphs effectively.

Preservice teachers with four-year science degrees had considerable difficulty conducting and reporting on a field research activity. My studies demonstrated that they had problems with operationalizing variables, recording and presenting data in inscriptions, and interpreting data and drawing claims from it. In part this is undoubtedly related to how “variables” are presented throughout undergraduate science programs as existing a priori and apart from the scientists own involvement, in relatively small numbers, and unambiguously related to other variables.

An issue related to the difficulty preservice teachers had in framing variables to study in their field investigation is that they then often utilized tables differently than did experienced researchers. Whereas field researchers use tables to organize and structure their data collection so that they do not miss recording an important piece of information, preservice teachers often used them only to present data and infrequently employed them as a tool in which to record data when they were conducting studies or experiments. Again, the design of the activities in which I engaged the student teachers meant there was little necessity to design record-keeping strategies to keep track of large amounts of information—a feature shared with most undergraduate science laboratory or research activities. This means that

preservice teachers experienced little need to design tables, especially since the cookbook-styled activities common to their undergraduate science program often provided tables and therefore pre-designated variables to complete. Therefore, when they needed to provide data tables as part of their own research assignments it is not surprising that they had difficulty structuring them so they were useful for collecting data.

Another consequence of the way in which undergraduates learn to think about variables from both lectures and laboratory activities is that they develop a reductionist, anthropocentric world-view which poorly represents the world experienced by organisms who react and respond within their own life-worlds. In part this occurs because the way variables are presented in lectures and textbooks suggests that relationships between variables are unambiguous and that “they exist as if in the ether,” which misrepresents and under-determines the complex relationships found in nature. However, in some ways even experienced field biologists do not effectively enact the study of variables from the perspective of the animal they are studying, but rather study the variables that are possible to study that are salient to them from a decidedly human perspective. The anthropocentrism regarding how organisms perceive their worlds reflects both the ways in which newcomers are enculturated to practices and the perspective of the domain itself, which traditionally has not encouraged taking this view.

The study of field biologists leads to a view of variables that differs from that prevalent in the laboratory sciences which better reflect the traditional myths about the nature of science. Research questions and variables often emerge from the initial work of field biologists as they pursue something of interest; these questions and variables change as a function of a researcher’s experience and familiarity with the territory. Yet all of the formal sources of information present field ecology studies as if the nature of the study and the variables being examined were determined before the research area was actually studied. These formal, de-personalized presentations of science offer a view of the conduct of

science to those who are learning about science which is at odds with the actual practice of it.

Apart from the effect that textbooks have on how students come to perceive variables, they also emphasize different inscriptions than those considered important in science. Often these common photographs and naturalistic sketches are so decontextualized that it is difficult to know what students are supposed to learn from them—especially when dynamic natural situations are presented in a static format. Their use in textbooks is also quite different from journals. Whereas journals leave little room for alternative interpretations of inscriptions (providing considerable detail), textbooks provide little information to help students interpret inscriptions. However, frequency of different inscriptions aside, the changes made to graphics in their move from journal articles to textbooks also further confounds their interpretation.

So far I have argued that students learn little about field research practices from their university classes, laboratory activities, or textbooks. The question then arises how students actually learn how to engage in the practices of the discipline? In this, the exchange of stories about field practices in informal settings (or informal presentations) and the prolonged engagement in field sites seem central to how these practices develop. It is through engaging in activities (either on one's own project or as an assistant on others) that a pool of experience is accumulated which contributes both to developing one's own field practices and the interpretative framework which emerges from field studies. One does not have to engage in the community of field ecologists for long to realize that variables emerge as studies progress, that relationships between variables are often weak (even when they are depicted in a graph with only a trend line), and that engaging in the community and its social practices of story-telling about field experiences is a vital part of becoming an effective field ecologist. It is this engagement that contributes to understanding the

discipline in a manner unlike that which is possible from the way in which undergraduate science programs are generally constructed.

Implications for education

Interpretation of inscriptions, understanding of concepts, and enacting of the everyday research practices of scientists are all interrelated and are all tied into having worked on projects in settings which are congruent with (although not necessarily the same as) those enacted by practitioners in their everyday work. This suggests that to best prepare student teachers (and then their students) presenting science as lectures or as a series of pre-formulated activities will not lead to an understanding of scientific claims. However, we must ask if we want the science that students learn to be merely a parallel of that which exists in the everyday work of scientists; for engaging in these practices does not necessarily mean that one develops a better understanding of biological natural phenomena. Just as scientists believe that natural phenomena have an underlying mathematical foundation and enact practices designed to search for these mathematical foundations, so too did those who were interpreting our graphs who were not scientists. This includes the student and practicing teachers who participated in my research. Such a view, however, is a distinctly Western way of knowing and framing nature. This view represents a way of making sense of phenomena that often excludes other ways of knowing and making sense of phenomena—making inclusiveness in our schools just that much more difficult to accomplish.

Current practices of science, especially in field biology, arguably develop reductionist worldviews rooted in the human perspective of the world. Numerous authors argue that scientific practices and communities are structured in a way that leads to exclusion from participation in science. This exclusion traditionally affected women but also those with a cultural perspective on knowledge different from the logo-centric (such as found in First Nations culture). Clearly this would be an undesirable component of the culture of science

for schools to promulgate. This is especially true since (future) teachers (unlike those with research experience) have few experiences with science which would help them to better understand (and teach) that natural phenomena often poorly fit the idealized mathematical relationships presented as claims in biological science (especially in textbooks).

Having student teachers improve their “knowledge” of science by taking undergraduate classes (and reading textbooks and journals) would do little to address the problems we in science education research often identify as being problematic—their so-called lack of conceptual knowledge—because science program graduates often also have trouble enacting such knowledge. Engaging student teachers in those courses (such as some jurisdictions now require) would do little to address these issues and would further entrench the reductionist, human-centered view that is off-putting to many who do not participate in science because they view knowledge differently. If science program graduates have difficulty constructing and conducting small research projects, interpreting graphs, and develop a reductionist anthropocentric view of nature and the organisms in it, then there is little to suggest that immersing student teachers in such a program would lead to outcomes other than those. Indeed, the fact that the latter perspective is prevalent in scientific communities may well be the cause for commercially non-existent cod stocks on the east coast, salmon stock problems on the west coast, and the myriad of problems currently associated with introducing genetically modified foods into the general ecosystem. If teachers are to be able to teach a critically reflective (as opposed to accepting view) of science, then solely relying on science departments to teach our future of teachers about science would appear to be short-sighted. Clearly, faculties of education need to engage student teachers in programs which will help them develop their understanding of the conduct of science in such a way that they enact it themselves, and scaffold them towards a critically reflective stance towards those very practices. How would such a teacher education program be structured?

Simply telling student teachers how to conduct “appropriate” investigations, how to conduct graph construction or interpretation, and even how to structure their own science classes does not increase their own competence at these activities or increase their competence in helping students learn the practices of science. For these activities to be best learned student teachers need to participate in a community which engages in these practices as a matter of course, and which is structured to encourage the social aspects of community which leads to these practices being “everyday.” To best help this community develop I suggest that student teachers need to engage in long-term research projects whose results they share and defend within a broader community using the representational and rhetorical tools utilized in scientific communities. By engaging in long-term studies, students will have the opportunity to develop their own insights, and from these develop their own research questions and variables. By engaging in a community in which they both present and argue for their claims, they will learn about knowledge construction in the sciences and the ways in which this is socially mediated. In part, the required critically-reflective component will develop because of the broad mix of people found in education programs. However, this alone will not be enough. Apart from engaging in the practices, these education programs will also need to encourage members to spend time reflecting on what those practices accomplish and the nature of the knowledge that arises from them.

At the risk of offending those in the laboratory sciences, I would also argue that studies of ecology or environmental science (or, as discussed in Chapter 11, environmental activist projects) offer the best discipline in which to engage students in long term study because of how little (relatively) is known in those domains and because of the situation specificity of possible outcomes. In physics and chemistry, student inquiries easily lead to results that contradict canonical scientific knowledge. This is a frequent teacher excuse for not enacting investigations in those subjects. On the other hand, because of the complexity of natural settings, ecological claims can be quite varied and still not run counter to standard

knowledge claims. In addition, extended studies of nature can be done with minimal equipment, and using local natural resources outside of the university setting.

By themselves engaging in such activities student teachers would also be learning how to engage their own students in similar activities. Perhaps by better understanding themselves how the “authority” of science is socially structured, they will be less inclined themselves to teach students using the authoritative methods of lectures and cookbook laboratory activities as if there was an absolute knowledge and methodology to pass from one person to the next. By engaging in inquiry activities congruent with the practices of science (whether as investigations or activism) they will be empowered themselves in their orientation towards what it is to know and do science and they will better understand how to help their own students understand science, its practices, and its claims.

I recognize how difficult the task is to re-orient how student teachers and teachers view science. This is related both to the seductive nature of their belief in science and to the issue of power and control; many teachers are loathe to surrender either from epistemological or behavioral perspective. In addition, student teachers are often impatient with engaging in in-depth activities themselves. I often found that they insist on being told rather than wishing to spend the time to develop an understanding. However just as one cannot be simply told how to interpret a specific graph, I also believe that it is a substantial task to effectively tell someone what the nature of science and its practices are such that they understand and enact those practices and interpret the work of scientists with that framework. I suspect that it is only by engaging students in research practices congruent with those of scientists, and reflecting on those, that they will develop an understanding of science and its claims, and be empowered to participate and engage with those concepts.

I began this dissertation by outlining how my experiences in ecology, sociology, and as a teacher influenced me to conduct the kind of research that I reported throughout the various chapters. Despite my extensive, four-year work of trying to come to understand the

appropriation of scientific research practices, I am not entirely clear about how what we better understand now can or perhaps ought to influence school and university instruction. So, rather than drawing hasty conclusions, I decided to continue to pursue the kind of work I have done so far and focus during the upcoming two years on the relationship between education and practice as part of a post-doctoral fellowship. In this work, I continue with the attempt to bridge my interest in science studies and science education and to contribute to our overall effort in understanding science and providing better learning experiences to science students at all level of their education.

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to G. Michael Bowen.

Sincerely,

Wolff-Michael Roth [<http://www.educ.uvic.ca/faculty/mroth/>]

Lansdowne Professor (applied cognitive science)

University of Victoria

currently:

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(Cognitive Neurosciences and Information Sciences)

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2. Here is the copyright information from the editor of journal RISE:

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