Learning to Write like a Scientist: A Study of the Enculturation of Novice Scientists into Expert Discourse Communities by Co-authoring Research Reports

By

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B.Sc. (Ag), University of Alberta, 1987

A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of

MASTER OF ARTS

in the Department of Curriculum and Instruction

We accept this thesis as conforming to the required standard

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ABSTRACT

This case study examined the co-authorship process in two research laboratories of different university science departments. The study focused on five writing teams, one in Biochemistry and Microbiology and four in Earth and Ocean Sciences. The role of the research supervisor, the role of the student (graduate and post-graduate), the interaction of the supervisor and the student, the activities and processes inherent in the co-authorship process, and the student's expertise, scientific writing, and entry into an academic discourse community were observed. Multiple sources of data and methods were used to document the activities and processes in the co-authoring of research reports; the alignment between the graduate student's or post-graduate student's and their research supervisor's beliefs about writing; and whether co-authorship helps the student become an expert science writer. Participants were given a questionnaire to ascertain their respective background experience in science and their beliefs about science writing and followed through the five-month drafting process of a research report manuscript. Meetings between research supervisors and students were observed and audio-taped, and field notes and reflective notes were taken. Edited drafts, including research supervisors' suggestions and students' responses, were collected. During their writing or soon thereafter, students were given part two of the questionnaire to establish the methods they used when they wrote. Finally, the participants were asked to reflect on their co-authoring experiences and to suggest any other activities that would aid students (research supervisors' response) or themselves (students' response) in becoming proficient science writers. Several activities and processes were found to be common across all co-authorship teams, including aspects of planning, drafting, and revising. Habits of mind, beliefs about the nature of science, and abilities to communicate the big ideas of science were evident in these activities and processes. Elements of scientific and writing expertise, facets of enculturation into scientific research and discourse communities, academic civility, and the dynamics of collaborative groups also were apparent. Audience and journal selection were surpassed in importance only by the writers' perceptions of the rigor of their scientific claims. Graduate and post-graduate students' beliefs about science and the role of science writing agreed with those of their graduate supervisors. The findings of this study indicate that co-authoring a research report is an authentic and meaningful learning experience that helps students learn to write like scientists.

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ACKNOWLEDGEMENTS

I wish to extend my sincere appreciation to Dr. Larry Yore. Larry, you were always there to encourage and guide me, and to share with me your knowledge of science and science literacy. I shall always remember with great fondness your kindness, patience, and generosity. I am also most grateful to Dr. Margaret Robertson, Dr. John Anderson, and Dr. Perry Klein for their knowledge and encouragement. Your thoughtful, insightful comments and suggestions have added a great deal to this study.

Many thanks go to the participants in this study who gave freely of their time and offered valuable insights into the world of scientific publication. I am in awe of your abilities and very grateful for your kind assistance and encouragement.

I am grateful to my 'partners in crime,' fellow students Pat Bright and Stewart Langton, who never failed to make life fun and interesting. Pat, Doug, Ian, and Laura Bright have become very dear and special to me, and I thank them for their kindness and support. Thank you as well to Connie te Kampe whose transcribing skills and wonderful sense of humour helped bring this study to completion.

Finally, I am very grateful to my family. I thank my husband Zack for his patience and love. Thank you for inspiring and encouraging me, and for easing my way. I thank my parents Margaret and Stanley Sware′ and my sister Jeannie Stanley for their constant love, encouragement, and generosity. I also fondly thank my parents-in-law Willie and Reva Florence for their love and kindness.

CHAPTER 1

OVERVIEW, FOCUS, SIGNIFICANCE, AND LIMITATIONS

Overview

Language is the lifeblood of scientific endeavour. Oral and written language are essential tools in doing and in reporting science. Yesterday's and today's scientific findings provide the basis for tomorrow's discoveries. Scientists contextualize their inquires and results within the work of others to augment their evidence and claims with established warrants. Hence scientists must commit their findings to paper, and they must do so with clarity and emphasis. Chaopricha (1997) maintained that in the biochemistry community, for example, "...any claim to the priority of discovery requires suitable, trustworthy, and persuasive methods for communicating the work that constitutes the claim to priority. Verbal or informal communication is not sufficient" (p. 12). Scientists construct their contributions on a foundation of other experts' established claims and effectively communicate their contributions to various expert and lay audiences.

More importantly, the rhetorical nature of scientific language requires experts to respond to their audience's feedback and to refine, revise, and reconstruct their knowledge claims as argument (Yore, 2001). Scardamalia and Bereiter (1991) identified supporting yet significant roles that reading and writing play in expertise "[reading and writing] are significant in almost all modern occupations – but more especially because they function at the growing edge of expert competence" (p. 191). Locke (1992) and Norris and Phillips (2001) described an even more essential role for language and writing in scientific expertise. Locke contended, "[Language] is not merely the empty vessel into which the contents of scientific thought is poured" (p. ix). Norris and Phillips asserted that writing is an essential part not only of the scientific conversation, but also of doing science.

> [R]eading and writing do not stand in a functional relationship with respect to science, as simply tools for the storage and transmission of science. Rather, the relationship is a constitutive one, wherein reading and writing are constitutive parts of science, or, to view the relationship in the other direction, science is in part constituted by reading and writing. (pp. 7-8)

Glynn and Muth (1994) investigated aspects of this constitutive relationship related to understanding the nature of science. They contended that the writing of a novice in science evolves and "becomes epistemic" (p. 1065). Conversely, Burton and Morgan (2000) described a constitutive relationship in which language influenced a discipline's epistemology. They maintained, "[The] language used in mathematical practices, both in and out of school, shapes the ways of being a mathematician and the conceptions of the nature of mathematical knowledge and learning…" (p.429).

Clearly individuals who aspire to expertise in any given scientific field must have the ability to transform their findings into text. They must then expose the text to the scrutiny of their peers, and subsequently be able to use peer criticism to refine and reconstruct their ideas. In accomplishing these goals, they are able to situate their work within existing scientific knowledge and discourse, to expand the boundaries of canonical science, and to situate themselves within the science community.

Initiation into a discourse community is a crucial event in an academic's career. Bazerman (1992) pointed to its importance, noting "each newcomer to a field must come to understand, cope with and place himself or herself within the evolving conversation" (p. 66). Bizzell (1992) described the benefits students acquire by being initiated into a discourse community: "Mastery of academic discourse lets students participate in the community primarily responsible in our society for generating knowledge" (Bizzell, 1992, p. 150). Aspiring scientists enrolled in graduate and post-graduate programs, for example, must strive to become proficient writers in and of science – and it is the responsibility of instructors, professors, graduate advisors, and research supervisors to ensure they have every opportunity to do so.

Few studies have focused on practical means of inculcating this expertise in novice science writers and enculturing new members into the science discourse community during graduate and post-graduate programs. Chaopricha (1997) studied co-authorship of research papers by research supervisors and their research assistants as a means of initiating graduate students into the biochemistry discourse community. It is the intention of this thesis research to study the co-authorship process in two science departments, observing the role of the research supervisor, the role of the student (graduate and post-graduate), the interaction of the supervisor and the student, the activities and processes inherent in the co-authorship process, and the outcomes for the student with respect to his or her expertise in scientific writing and entry into his or her respective academic discourse community.

Study Focus and Research Questions

Graduate students in masters, doctoral, and post-doctoral science programs are expected to move successfully from novice to expert writer, emerging at the end of their programs able to do research and to produce acceptable research reports and journal articles. Some effort has been made to give students this experience in lieu of producing a thesis or dissertation. Rather than writing in a more traditional format, many science students are opting for theses and dissertations comprising a series of research papers (Pearson, personal communication, 2001).

The research questions under study are:

1. What are the activities and processes inherent in the co-authorship of research documents?
2. How do the graduate student's or post-graduate student's and the research supervisor's beliefs about writing agree or disagree?
3. Does co-authorship help the student become an expert science writer?

The purpose of the research described in this thesis is to determine how graduate and post-graduate student writers, one in biochemistry and five in earth and ocean sciences, become encultured into their respective discipline-specific discourse communities. How do these novice writers learn to write like scientists, thus facilitating full entry and acceptance into their respective disciplines? For each writer, the study focuses on a single enculturative activity, namely the co-authorship of a journal paper with his or her research supervisor.

Significance of Study

This research will provide insight into graduate and post-graduate science students' experiences in writing. It will bring to light those activities and processes that prove effective in helping students become proficient writers in and of science. It also will uncover activities that are not helpful in this regard; indeed some activities may be considered counterproductive to gaining expertise in writing. This information may help explain why some graduate students do not complete thesis and dissertations (about 26% of MSc students and about 21% of PhD students in Biochemistry, Microbiology, Geology, and Physics). Many of these students opt instead for the "all-but-thesis" or "all but dissertation" designation (Sharpe, 1997). Results of this research will be valuable to research supervisors in science who seek to help students become better writers. As well, this information will inform and aid curriculum planners in the design of technical/science writing courses for post-secondary institutions.

Limitations of the Study

The greatest limitation of this study, other than those generally associated with case study methodology, is the timeframe in which it was undertaken. Manuscripts are seldom produced according to a strict schedule. Indeed, the iterative nature of scientific research and writing may mean that the writer must go back to the laboratory or field several times to address problems and to collect more evidence made apparent by draft manuscripts. As well, life sometimes gets in the way of research: writing simply does not progress as planned because other activities take precedence. For instance, two of the participants took time away from the manuscripts they were writing to prepare for candidacy examinations, and to prepare slides and posters for scientific meetings. Hence, some of the writing activities could not be followed to fruition in the time allotted for completion of this masters' study.

My presence during the meetings did create somewhat of an observer effect, although the research was not severely limited by it. The participants did not appear to feel pressured by my timelines, nor did they undertake unusual activities or interact in noticeably affected ways.

CHAPTER 2

REVIEW OF LITERATURE

Introduction

The first portion of the literature review includes a discussion of three main components of science literacy: habits of mind, the big ideas of science (including social constructivism and the nature of science debate), and communications to inform and persuade (Hand, Yore, & Prain, 1999). Discussion of the last component comprises information about disciplinary culture and language; genre and genre knowledge; intertextuality and citation; hedging; and peer review. These ideas are followed by an examination of expertise in science writing, which is prefaced a discussion of the characteristics of an expert, including how he or she learns. Finally, the results of studies by Yore, Hand, and Prain (2000) and Yore, Hand, and Florence (2001) concerning the qualities of an expert science writer are reviewed and discussed.

Contemporary Literacy and Science Literacy

Morris and Tchudi (1996) explored elements of literacy including the relationships between literacy and popular culture; literacy education; language, voice and the literate citizen; and the prototypical literate citizen. Two of their conclusions are especially salient to a discussion of science literacy: 1) literacy comprises three elements: basic literacy (the 3Rs); critical literacy (the ability to analyze, interpret, and explain text); and dynamic literacy (the ability to take action on text), and 2) the literate citizen communicates and works collaboratively, is attentive to language and adaptable to its changes, can think critically, creatively and imaginatively, and uses technology to good advantage.

Norris and Phillips (2001) described two senses of literacy. "In its fundamental sense, literacy means being able to read and write. In its derived sense, literacy refers to being knowledgeable, learned, educated…" (Norris & Phillips, 2001, p. 3). Applied to the notion of science literacy, a fundamental sense of literacy would equate to the ability to read and write in science, while a derived sense would indicate knowledge of and learnedness in science, in that the person could construct, apply, and criticize science in a pragmatic context.

Norris and Phillips argued that individuals require both senses of literacy to be considered science literate; the fruits of scientific labour could neither be transferred, by being written, nor interpreted, by being read, in the absence of fundamental literacy. Authors of *Science for All Americans* (AAAS, 1993) described science literate individuals as having "the ability to share ideas and information with fidelity and clarity, and to read and listen with understanding" (p. 138). They can participate fully in the broader debates about science, technology, society, and environment issues (CMEC, 1997; NRC, 1996).

Norris and Phillips offered several descriptions of science literacy that included such components as "knowledge of what counts as science…appreciation of and comfort with science, including its wonder and curiosity…abilities to think scientifically…to use scientific knowledge in problem solving ability …[and the ability] to think critically about science and to deal with scientific expertise…" (pp. 4-5). Hand, Yore, and Prain (1999) described science literacy as "the cognitive abilities and emotional dispositions to construct science understandings, the big ideas of science, and the communications to inform people about these big ideas and to persuade them to take informed actions" (p. 1). Cognitive abilities and emotional dispositions comprise the habits of mind needed to understand ontological assumptions of science and the epistemological criteria of science knowledge. The big ideas of science include major unifying conceptions of science and beliefs about the ontology and epistemology of the nature of science. The final constituent, ability to communicate, includes the effective expression of claims, evidence, and warrants, which underlie knowledge building.

Flower (2000) contended "It is generally agreed that a science-literate person possesses a basic vocabulary of scientific concepts and terms, knowledge of the processes of science utilized to test our models for making sense of the world, and an appreciation of the effect of science and technology on society, to a degree sufficient to participate in dealing with the increasingly large number of science- and technology-laden public policy questions we face" (p. 38). Flower's science-literate person is an informed, critical thinker and an astute decision maker, and is thus able to participate fully in public debate of scientific issues.

These contemporary descriptions of science literacy contain elements of Morris and Tchudi's basic literacy, critical literacy and dynamic literacy. Accordingly, scientifically literate people possess basic literacy -- they can read and write; critical literacy -- they have the local/specific/domain knowledge to analyze, interpret and explain text; and dynamic literacy -- they are able to act and to use the knowledge they glean from scientific texts.

Habits of Mind

Hand, et al (1999) described the first element of science literacy as the cognitive abilities and dispositions to construct science understanding – in short, habits of mind. Johnston (1999), in describing the work of Kuhn, et al (1995), noted that habit of mind in scientific thinking was one of three interrelated areas of understanding to be developed in science education. He described habits of mind as having both metacognitive and metastrategic aspects. Volkman and Eichinger (1999) refer to habits of mind as a way of thematically representing the personal and social qualities of doing science (p. 142). They list four habits of mind outlined in *Science for all Americans* (AAAS, 1989): curiosity, openness, skepticism, and communication. Volkman and Eichinger pointed to the essential nature of communication in demonstrating habits of mind. "As new ideas are communicated through presentations, papers, and journal articles, scientists continue to exercise the habits of curiosity, skepticism, and openness. As new ideas are tested, the community judges their merit" (Volkman & Eichinger, 1999, p. 144).

Perkins, Jay, and Tishman (1993) listed dispositions as one of the constituents of good thinking. "In general, dispositions can be defined as people's tendencies to put their capabilities into action. Mindfulness can be considered a disposition because it has to do with how disposed people are to process information in an open, alert, flexible way…" (Perkins, et al, 1993, p. 75). The authors argued that thinking dispositions distinguished good from average thinkers. Good thinkers possess mindfulness, invest mental effort, and take intellectual risks.

The Big Ideas of Science

Beliefs about the second component science literacy (Hand, et al, 1999) -- the big ideas of science -- often are manifest in beliefs about the nature, structure, and key knowledge claims of science. Yore, Hand, and Florence (2001) described science as

> ...people's attempt to search out, to describe, and to explain patterns of events in the natural universe....The knowledge claims and explanations of causality are tentative and open to further inquiry and new supportive or discrepant evidence....Science distinguishes itself from other ways of knowing and from other bodies of knowledge through the use of empirical standards, logical arguments, plausible reasoning, and skepticism to generate the best temporal explanations possible about the natural world (Johnson-Laird, 1988; McComas, 1998). (pp. 3-4)

This view stresses the tentativeness of scientific claims. Explanations are put to the test and may be supported. However, they are not everlasting; rather they are temporal, the best interpretations posited thus far. Furthermore, the knowledge claims are related (not isolated ideas) and form integrated conceptual networks. Scientists use canonical knowledge claims as warrants to augment evidence when making claims and their patterns of argument explicitly illustrate the evidence-claims-warrants linkages.

Not all philosophers of science agree with this perspective, nor do they agree with a universal view of science. Lederman (2001) dealt with conflicting philosophies about the nature of science by positing that there was some agreement across views of science in that there were three viewpoints: science as induction -- just give me the facts; science as falsification -- just give me the imperfect facts; and science as relativistic -- my facts are as good as yours. An understanding of these competing views of science is one of the components of science literacy (NRC, 1996).

Science as induction equates scientific knowledge with truth. This perspective is associated with an absolutist view of science, wherein knowledge is confirmed through sensory evidence or the power of intellect. The scientist is objective and scientific inquiry follows a series of "typical steps" (McComas, 1998, p. 57). Physicist Edwin Hubble (1954) provided a positivist description of the scientific method. "[The verification of predictions] is the very essence of the scientific method, and serves to control the powerful but dangerous instrument of inductive reasoning. When theories cannot be tested, their appeal is largely aesthetic" (Hubble, 1954, p. 12). McComas (1998) elaborated on the problem with induction "...only by making all relevant observations throughout all time, could one say that a final valid conclusion can be made" (p. 58). He further asserted that deduction (Hubble's verification of predictions) can test a law and ultimately establish or refute its validity.

Science as falsification is commonly described as an evaluativist view of science. The aforementioned description of science (Yore, Hand, & Florence, 2001) demonstrates this viewpoint, which recognizes that scientific knowledge is temporary and based on explanations that best fit the warrants and evidence at hand. The hypothetico-deductive reasoning used to acquire the knowledge in this epistemological view is coloured by the thinker's prior experience and subject to society's beliefs and values (Yore, 1992). A scientist who considers himself or herself evaluativist seeks objectivity, while at the same time acknowledging his or her own biases, experiences, and limitations.

Wenham (1995) expressed an evaluativist opinion of the nature of science. "The facts, concepts and theories which make up scientific knowledge are not permanent nor beyond dispute. They are much more like a report on progress so far, which future investigators will modify and even, maybe, contradict" (Wenham, 1995, p. 1). McComas (1998) stated in his observations about scientific objectivity:

> Scientists, like all observers, hold myriad preconceptions and biases about the way the world operates. These notions, held in the subconscious, affect the ability of everyone to make observations. It is impossible to collect and interpret facts without any bias. ....two individuals reviewing the same data would not be expected to reach the same conclusions. Not only does individual creativity play a role, but also the issue of personal theory--laden observation further complicates the situation. (p. 62-63)

Plainly, the role of the individual and his or her prior knowledge figure into the evaluativist epistemology. Nonetheless, generally accepted criteria for judging validity and the consistency of both experimental and observational evidence are central to these beliefs about the nature of science. Explanations about the natural world "based on myths, personal beliefs, religious values, mystical inspiration, superstition, or authority may be personally useful and socially relevant, but they are not science" (NRC, 1996, p. 201).

Science as relativistic is commonly referred to as a postmodern viewpoint in which knowledge is a construct of culture, society, and history. Postmodernists' explanations of science reflect lived experiences, personal beliefs, and the socio-political context of the day. Individuals construct their own knowledge of science, based on their own personal criteria. The postmodernist viewpoint assumes that all knowledge claims and interpretations are equally valid and therefore should not be judged by external agents.

Morse (1995) described an epistemology known as feminist postmodernism. Feminist postmodernists contend

> …there may in fact not be a universal experimental reality; that the dozens of identities that humans claim, such as race, sexual orientation, IQ, gender, class political leanings, and others all confuse and make impossible science's quest for universal truths. Rather than throw out science, postmodernists would deconstruct all existing scientific 'knowledge' based on the historical factors and contingencies in place at the time the knowledge was gained. (p. 25)

Scientists who adhere to feminist postmodernism are not, nor do they aspire to be, objective. Olson (1999) contended that "[postmodernism] …treats assertions of scientific fact as indeterminate texts constructed by readers" (p. 2).

Postmodern beliefs about the nature of science are sometimes described as "standpoint epistemologies" (Ward, 1997, p. 774). Ward explained that in these epistemologies "...gender, ethnicity, culture, sexuality or some other group- or site-specific element of fact-production are ultimately responsible for both the form and content of knowledge...[and] that all knowledge is localized perspective and all interpretations are mediated by and can be reduced to the linguistic or social characteristics of the groups which produce them" (p. 774).

Not surprisingly, standpoint epistemologies come under fire from those who believe that universal truths do exist and can be defined. Cobern and Loving (2001) discussed the inclusion of multicultural viewpoints in school science curricula. They concluded that educators ought to consider indigenous knowledge about natural phenomena a different kind of knowledge and value it for its own worth, rather than including it in mainstream scientific knowledge, and thus allowing Western science to "co-opt and dominate" it (p. 51). Cobern and Loving contended that indigenous knowledge could thus "maintain a position of independence from which it can critique the practices of science and the Standard Account" (p. 51).

The preceding discussions of the nature of science make one thing clear: there is no universally accepted viewpoint of the nature of science. Lawson (2000) may speak for many -- or perhaps only for himself -- in his description of the predictive power of evidence-based science ideas.

> In the final analysis, ideas -- including scientific hypotheses and theories -- stand or fall, not due to social negotiation, but due to their ability to predict future events. ...This is not to argue that social interaction can not be helpful. It can be helpful in many ways (e.g., in sharing and clarifying problems, in suggesting alternative hypotheses, in suggesting possible test conditions, in

criticizing conducted tests, in collecting and analyzing results). But in the end, feedback from the physical world is the ultimate arbitrator of which knowledge claims are accepted or rejected. (p. 587)

Scientific Communication: Doing and Reporting Science in a Socio-cultural Context

A discussion of the ability to communicate the big ideas of science, the final component of science literacy (Hand, et al, 1999), must be prefaced with a discussion of science, society, and language. Hjørland and Albrechtsen (1995) asserted that effective communication required an easily interpreted and socially based language of science. They argued that from the absolutist perspective, language constitutes labels and has no "contributing role in the perception of reality, but is functionally limited to communicating already established knowledge in the individual" (p. 408). Therefore, language so described is detached from social or cultural considerations.

In direct opposition to this traditional view, social constructivists believe that socio-political forces take the most influential role in knowledge production. Phillips (1997) asserted: "...one of the key issues raised by the social constructivists is whether or not our public bodies of knowledge -- especially the sciences -- are about something, and whether or not they are only the handiwork of socio-political forces and biases; social constructivists want to challenge the view that external nature plays a decisive role in shaping what we know about it, that nature somehow 'leaks in' (Latour, 1992, p. 276) and acts as a constraint in our knowledge constructing activities" (¶ 24). Hruby (2001) pointed out "[Phillips' social constructivism]...may be usefully understood as being about the way knowledge is constructed by, for, and between members of a discursively mediated community" (p. 51). Knowledge is constructed by society and language is used to negotiate meaning and express consensus.

Hjørland and Albrechtsen argued that a more modern, holistic view has been posited, one that recognizes "the importance of language in the perception of reality, thereby introducing a historical, cultural, and social dimension in the theory of science. Reality cannot be understood naively by the unprepared and isolated subject. It is the knowing subject, who is formed by history and culture, including the concrete development in specific knowledge domains, who has the possibility to perceive the reality" (p. 408). Hence if language is used to construct knowledge, then knowledge must be influenced by, though not entirely dependent upon, the society in which the language exists.

An interactive-constructivist viewpoint proposed by Yore (1999) may be considered just such a modern view of science. It is a hybrid, comprising portions of a positivistic-mechanistic viewpoint and a social constructivist-contextualistic viewpoint, and it is generally evaluativist in epistemic terms. Proponents of this perspective hold that nature is the judge in decisions of knowing; however, with respect to the psychological locus of mental activity, they recognize that both group interaction and personal reflection and integration enter into scientific debate and knowledge building.

It would seem reasonable, then, to assume that the tentativeness of science would make scientific communication open to scrutiny. Furthermore, scientists would necessarily have to indulge in rhetoric, the art of persuasion, to have their ideas heard and considered in the larger conversation. Bazerman (1998) makes a case for a rhetoric of science, first noting that some rhetoricians and scientists would see science as "knowledge that rises above the situated and purposeful use of language" (¶ 4).

> Within the bounded discursive world, of science, an intertext of cited works or a literature defines a gradually transforming discursive space within which new claims vie for acceptance, judged by an epistemic court of insider specialists. This enclosed communication system must then represent itself and its knowledge outward to the other public realms, to spread its influence, to petition for resources, and to establish and maintain its boundaries and authority. So a rhetoric of science can study an internal discourse of claim making, a socially contentious discourse of boundary creation and maintenance, and an outward-facing, interest-driven discourse of professional representation. (¶ 7)

Locke (1992) rejected the official and traditional language of science as a "neutral voice…a transparent medium for recording of scientific facts without distortion" (p. 112). Similar to Bazerman, Locke claimed science as a rhetoric: "… although that voice has not yet been fully characterized, its vaunted objectivity is not cause but effect, rhetorical effect. Further, this rhetorical effect, this inevitable concomitant of the chosen voice of science, operates on those who use, as well as those who heed, that voice. Scientists, as do we all, think in their own voice and are affected by its rhetoric" (p. 112).

Thus the world in which scientists work, read, and write has its own voice, in the most liberal sense of the word. Effective writers in and of science must seek to understand more about the audiences who hear this voice. In terms of their own disciplines, they must be aware of the social/political context of the discourse community, a space in which the community's goals and values exist (Beaufort, 2000).

Addressing one's peers is not as simple as it would appear. Berkenkotter, Huckin, and Ackerman (1989) described the scientific writer's sometimes onerous task

> Scientists do not simply 'let the facts speak for themselves,' but must constantly appraise and reappraise the rhetorical situation in which they are writing. They must fashion their claims and choose their words carefully, and must also be concerned with presenting a persona that is situationally appropriate. These rhetorically-based strategies figure significantly in scientists' writing and revising processes, since a writer's claims are evaluated by peers within the framework of community consensus. (p. 3)

Broad knowledge of the culture of the discipline helps the scientist appraise the rhetorical situation and strategize the best ways of communicating his or her ideas. Flowerdew (1995) defined disciplinary culture as the "theories, concepts, norms, terms…of a particular academic discipline" (p. 366). Fortunately for writers of science, noted Flowerdew, "…perhaps the most obvious way to recognise a discipline is through its specialized vocabulary" (p. 366). Harrison and Stephen

(1995) argued that disciplinary discourse communities had special ways of knowing, believing and persuading. “The fact that such conventions are held in common means that experienced writers within the discourse community are able to draw upon them for knowledge about what will count as appropriate language, appropriate evidence, and appropriate reasoning” (p. 595).

Flowerdew (1995) argued that from a linguistic point of view, a relationship existed between the structure of a body of knowledge and its discourse and related structures. Beaufort (2000) claimed a direct link between a text's form and its function – genre -- within a community, adding that this link extended to the text's "status relative to other texts routinely produced in the discourse community" (¶ 8). Berkenkotter and Huckin (1995) defined genres as "…the media through which scholars and scientists communicate with their peers. Genres are intimately linked to a discipline's methodology, and they package information in ways that conform to a discipline's norms, values, and ideology" (p. 1). They further used the term genre knowledge to "refer to an individual's repertoire of situationally appropriate responses to recurrent situations..." (p. ix)

Scientists may use knowledge of genre to make a case for novelty, while situating their findings within or in contrast to established research procedures and canonical knowledge claims (Berkenkotter & Huckin, 1995, p. 45). Authors of scientific research reports for a peer reviewed journals most often situate their findings through citation of existing research that "establishes the intertextual linkages that diachronically connect scientists' laboratory activity to significant activity in the field, and thus serves to establish a narrative context for the study to be reported" (p. 47).

Geisler (1994) referred to recognition and the situation of new information with respect to established findings as scientists "codifying a context for their work. ...To be successful, scientists need to characterize the previous literature in such a way that their own results appear to be a natural extension of the field's current state of knowledge. In other words, scientists must construct a narrative of their field that shows their own work to be the appropriate next event" (p. 15). Amsterdamska and Leydesdorff (1989) discussed the importance of citation and intertextuality. "Thanks to this integration [of the new claim] the innovation -- no matter how trivial, or how original -- is not just another loose fact added to the heap but rather an extension of a thread, a new knot, a strengthened connection, or alternatively a bit of unraveling, an indication of a 'hole,' a bit of reweaving, etc." (Amsterdamska & Leydesdorff, p. 451). In part, intertextuality reflects the interdependent structure of scientific knowledge that stresses knowledge networks rather than isolated concepts. Chaopricha (1997) described the valued role of citation in biochemistry writing as "scholarly bricklaying" (p. 16).

Nonetheless, the interweaving of new findings with established results does not necessarily insure the scientific writer's credibility within the community. Writers must seek to insinuate their findings into the community with full regard to the extensive power of the discipline's "gatekeepers" (Burton & Morgan, 2000, p. 431). Flower (2000) described the trepidation with which new findings are presented to the academy. "Upstream, tentativeness; downstream, factual claims" (Flower, 2000, p.

41). Writers often use a device called "hedging" to introduce these provisional claims (Geisler, 1994; Hyland, 1995; Hyland, 1996a; Hyland, 1996b). Hyland (1995) pointed to three main purposes of hedges.

> First hedges allow writers to express propositions with greater precision in areas often characterized by reformulation and reinterpretation ...The second reason concerns the writer's desire to anticipate possible negative consequences of being proved wrong. ...Finally hedges contribute to the development of the writer-reader relationship, addressing the need for deference and cooperation in gaining reader ratification of claims. (p. 35)

Hedges help science writers indicate to readers that their view of science and their arguments are speculative or that they push the boundaries of canonical science. Hedges are valuable, but nevertheless must be used discerningly, especially by the novice writer. Over use may indicate too much uncertainty, while judicious use indicates the writer has some confidence in his or her findings and also that he or she is aware of the discipline's rhetorical traditions. Hyland (1996b) contended "Basic writers invariably require training in the appropriate use of hedging, and foreign learners in particular find the expression of commitment and detachment to their propositions extremely troublesome" (p. 278). Geisler (1994) included hedging in her discussion of metadiscourse or "discourse about discourse" (p. 11) in science writing. She asserted that metadiscourse is used to establish a writer-reader connection within the writer's context. "[S]cientists as writers expect to speak forward to the projected context in which their work will be read and interpreted. For this reason...scientific texts [are] unusually laden with metadiscourse that directs implied readers in their interactions with the texts' claims: directions for assessing the validity of those claims (hedges) and directions for interacting with the text itself (commentary)" (Geisler, 1994, p. 25).

Editorial referees (peer reviewers) are often the first to encounter this metadiscourse-laden text, and they are generally considered to be the most critical readers of academic texts. Writers negotiate with referees, the disciplinary gatekeepers, to have their claims included in the authorized science. "Although peer review is not infallible, it remains the primary means through which authority and authenticity are conferred upon scientific and scholarly papers by journal editors and the expert judges they have consulted" (Berkenkotter & Huckin, 1995, p. 62). Meyers (1985) pointed to the importance in peer review of adequately established warrants. "The same claim may be considered 'speculative' or 'well defined', a 'highly significant' advance or a 'well-known' observation, depending on the body of literature into which it is placed and the audience which is to read it" (Berkenkotter & Huckin, 1995, p. 596). Meyers further contended that authors who wish to introduce novel claims must be aware of the negotiation involved in the form-function referential debate: authors attempt to bend the form to fit their ideas, while referees use the form to situate the author's ideas in the literature. "[T]hey are arguing not over the writers' failure to use the correct format but over the type of the claim and the importance to be accorded to it" (p. 597).

Sinding (1996) claimed that restructuring an article, that is, selecting an alternative form or venue for its presentation, could gain its acceptance. She posited that the review article format might have utility in this regard. Original experimental reports are reconstructed and recontexualized, and new knowledge claims are introduced in reviews, as well as in book chapters, encyclopaedias, or popularizing journals. Finally, Berkenkotter and Huckin (1995) acknowledged the value of peer review while recognizing its constraints. "Peer review can therefore be seen as a social mechanism through which a discipline's 'experts' maintain quality control over new knowledge entering the field. Quality control is, of course, a form of social control, and those who argue its utility share assumptions about the function of the referee system" (Berkenkotter & Huckin, 1995, pp. 62-63). Some audiences see peer review more as a way to maintain the authority and power structure of the members of a discipline or academic community than as a method of ensuring scientific rigor and authenticity.

Expertise

Clearly, those who wish to become expert science writers, and perhaps join the powerful few who act a disciplinary gatekeepers, need to understand the nature of expertise. The following section of this review is devoted to expertise and comprises a discussion of the characteristics possessed by experts, how they learn, and how they use both cognitive and metacognitive strategies to press the boundaries of their expertise.

The Nature of Expertise

The nature of expertise is highly contextual, thus making it difficult to define (Bereiter & Scardamalia, 1993; Holyoak, 1991). Pointing to "a disconcerting lack of constancy in the correlates of expertise", Holyoak (1991) contended that "there appears to be no single 'expert way' to perform all tasks" (p. 309). Hence, rather than attempting to define expertise, Bereiter and Scardamalia sought to characterize experts. They considered the differences between the careers of experts and nonexperts. "[The career of an expert] is one progressively advancing on the problems constituting a field of work, whereas the career of the nonexpert is one of gradually constricting the field of work so that it more closely conforms to the routines the nonexpert is prepared to execute" (p. 11). Therefore, experts exist in an expert subculture, that is, an environment or community that "embodies ideals and goals that direct the process of expert development" (Bereiter & Scardamalia, 1993, p. 104), and adaptation in an expert subculture requires general agreement with and pursuit of group goals (p. 105).

However, identification with a group and acknowledgement of group goals does not preclude independence. Bereiter and Scardamalia (1993) explained that "[A]n expert community, we might say, is one in which to conform is to grow (although to grow is not necessarily to conform)" (p. 105). Irrespective of this tolerance for non-conformity, however, those who pursue expertise must grow in their pursuit of excellence. In general, growth in expert communities takes the form of progressive problem solving in response to pressing issues of the discipline and the need for increased competence. Yet increased competence involves more than stacking additional skills and knowledge on pre-existing competencies (Holliday, Yore, & Alvermann, 1994). The expectation that community members will continuously use their unique talents to tackle new problems and acquire greater proficiency in their fields is inherent in expert communities, and such anticipation of growth leads to internal tension. The expert is not allowed to be comfortable with his or her current expertise, and, as a result, constantly pushes the boundaries of his or her knowledge and competence.

How Do Experts Learn?

Patel, Glaser, and Arocha (2000) studied novice and expert medical practitioners and found that novices had less ability to self regulate and to problem solve.

> Through their extensive experience, experts develop a critical set of self-regulatory or 'metacognitive' skills, which controls their performance and allows them to adapt to changing situations. For example, experts monitor their problem-solving by predicting the difficulty of problems, allocating time appropriately, noting their errors or failure to comprehend and checking questionable solutions. Novices are less understanding of task demands and how these match their capabilities, and this prevents them from tackling problems strategically. When they reach an intermediate stage in learning, they give more signs of self-regulation: they plan steps effortfully and explicitly before executing them and evaluate them afterward. By the time

they become experts, these self-regulating skills will be so well practised that they are effortless. (¶ 11)

Other studies of experts and novices have pointed to a difference in the capacity of each group to learn new information in their fields of work or study. Daley (1999) discussed this phenomenon in her study of how professional nurses learn. She investigated the connections among "expertise, experience, learning, and knowledge" (p. 3), and found that novice nurses relied on concept formation and assimilation in their learning. Expert nurses in Daley's study had markedly different experiences. "Expert learning … was identified as a constructivist process using active concept integration and self-initiated strategies…experts were able to articulate systemic issues that affected their learning, whereas novices identified disparate individual issues" (Daley, 1999, p. 133). Daley's results mirrored the findings of Patel, et al (2000), that is, compared to novices, experts exhibited greater levels of self-regulation and metacognition. They showed more self-awareness and initiative and were more likely to deconstruct experience relative to the learning/practice environment.

Bereiter and Scadamalia (1993) referred to case studies of piano students (Ghent, 1989) and medical students (Tal, 1992) in their discussion of expert and non-expert learning. Expertlike students used metacognition to solve problems and to accomplish their goals. Novices simply tried to make new material fit into existing patterns. Bereiter and Scardamalia gave an example from Ghent's study of music students.

> The [novice] student's approach to an unfamiliar kind of music was to find the best fit between it and what he already knew, and to be satisfied with that. The expertlike student approached a new piece of music as a problem to be formulated at the highest level. This meant that, instead of fitting the task to existing competence, the expertlike student had to extend existing competence in order to fit the requirements of the task. ...The best fit strategy deals with the immediate problem, perhaps quite effectively, but it does so in a way that minimizes new learning. The expertlike approach results in new technical skills and new musical concepts. (p. 157).

Bereiter and Scardamalia (1993) referred to the novice's use of best fit strategies to match new information with existing knowledge as "direct assimilation" (p. 169). In using these strategies, the novices fail to ameliorate deficiencies such as misconceptions and oversimplifications in their prior knowledge. In contrast, experts use "knowledge building schemas" (p. 171) to accommodate the new demands with networks of knowledge and abilities. The schemas both acknowledge and work to remedy these insufficiencies. A knowledge-building schema "lends itself to provisional interpretations, to keeping questions open, and to actively pursuing fuller understanding" (p. 171).

Holyoak (1991) described an expert's metacognitive processes in his discussion of good judgment.

> In general, an expert will have succeeded in adapting to the inherent constraints of the task. If the task can be done more efficiently by forward

> search, the expert will search forward; if backward search is better, the expert will search backward. If certain patterns of cues are crucial to performing the task well, the expert likely will perceive and remember them; if patterns are not so important, the expert will not selectively process them. (p. 309)

Holyoak indicated that the expert is able to metacognitively circumvent constraints by searching backward, in an iterative fashion, or forward, out of the box, in search of a new possibility. Perkins, Jay, and Tishman (1993) coined the term "mindware" in their discussion of factors that comprise good thinking. "[Mindware] refers to whatever learnable processes, schemas, sensitivities, attitudes, and so on, foster good thinking" (Perkins, Jay & Tishman, 1993, p. 68). They outlined three views of mindware. In the dominant general processes view, "mindware consists mainly in processes supported by skills and strategies, activated by a stimulus of the situation and by calls to subprocesses. …The story line of an ideal example of thinking can be characterized by top-down" (p. 83). In the expertise view, "mindware consists largely of content-specific knowledge and processes; activated by the nuances of the context, contributing through the context-specific knowledge of expertise, and acquired through situated learning. The story line of thinking may be characterized as bottom-up" (p. 83). Perkins, et al offer a third "synthesis" view which includes general processes, strategies and skills, and specific features of expertise including abstract conceptual structures and dispositions (p. 83). The synthesis viewpoint is neither bottom up nor top down. Similar to Holyoak's (1991) description of adaptation to constraints, mindware in this situation is flexible and makes best use of the individual's strengths and experiences. "This expanded ontology leads to more diversified answers to how mindware become activated, make their contribution, and get acquired. An appropriate story line for thinking may be called coalescence, in which the particular situation evokes some kinds of mindware, which draw in others in flexible ways specific to the occasion" (Perkins, Jay, & Tishman, 1993, p. 83).

Experts are continuous learners: they are constantly testing their abilities to think critically and to solve problems. Thus "for experts, the problems of insufficient prior knowledge never go away. ...The expert track of development keeps rising toward levels of increasing complexity of performance and understanding. This means that present knowledge is always superficial, simplistic, and fragmented relative to the knowledge the expert is trying to achieve" (Bereiter & Scardamalia, 1993, p. 175). Experts' dissatisfaction with the status quo and desire for cognitive growth is indeed what makes them experts: greater scope and extent of learning in any field of endeavour should lead to better understanding, which in turn could be expected to enhance expert performance. General and specific domain knowledge is necessary, but not sufficient, as experts acquire not only increased conceptual understanding, but also flexible and more powerful metacognitive awareness and executive control of this knowledge and its potential application.

The Expert Writer

The characterization of a writer as expert is fraught with difficulty. Faigley (1986) stated, "From a social perspective, a major shortcoming in studies that contrast expert and novice writers lies not so much in the artificiality of the experimental situation, but in the assumption that expertise can be defined outside of a specific community of writers. Since individual expertise varies across communities, there can be no one definition of an expert writer" (p. 535). Carter (1990) argued that to be considered an expert, a writer must possess both general knowledge of writing and domain-specific "local" knowledge of writing (p. 269). Carter stated, "Social theorists define an expert writer as one who has attained the local knowledge that enables her to write as a member of a discourse community. ...However, like most academic dichotomies, I think this one is also false: neither the general nor the local perspective alone provides a complete picture of the complexity of writing" (p. 266). Carter posited a pluralistic perspective in which both types of knowledge are present. Similarly, Joliffe and Brier (1988) argued that knowledge is exhibited by the presence of well-developed written schemata that indicates good conceptual understanding of and experience with the subject, within the specific domain.

Ferrari, Bouffard, and Rainville (1998) were able to identify some characteristics of good, though not necessarily expert, writers. Good writers in their study had better discourse knowledge; in particular, they were better able to construct a comparative text to organize and contrast their ideas. Good writers waited longer before they began to write; they wrote longer texts of better quality and were better able to judge the structural organization of their texts. Both good and poor writers wrote recursively. "Specifically, good and poor writers did not differ in how often they modified the form or content of their texts, nor in when they made changes during the writing processes, or in any of the other directly-observed indices of writing activity; nor did they differ in whether they made a final revision of their text before handing it in" (Ferrari, et al, 1998, p. 484). Ferrari, et al described this similarity as self-regulation of the "surface linguistic aspects" of writing (p. 485). Good writers took these metacognitive tasks one step further "…good writers also base their self-regulation on a deeper knowledge of the task (e.g., knowledge of different types of discourse structures that poor writers seem to lack)" (p. 484).

Bereiter and Scardamalia (1987) found that expert writers differ from their novice counterparts in the way in which they use writing. Novices use writing to tell knowledge, while experts use writing to build or to transform knowledge. Experts use metacognitive awareness and executive control to integrate domain expertise and rhetorical expertise; the latter component comprises knowledge of the appropriate discourse community. Experts strategically move between the content domain and the rhetorical domain as required and with ease to effect knowledge building. Geisler (1994) supported an interactive relationship between domain and rhetorical knowledge, asserting "One of the most important lessons of recent scholarship on literacy in the professions is that whenever expert practice is truly present -- when knowledge is treated as something to be constructed rather than found -- both rhetorical process and domain content will necessarily be involved" (p. 228). Bereiter and Scardamalia (1991) referred to this recursive action as a "dialectical process that serves to advance domain knowledge" (p. 190). Keys (1999) suggested that in managing this process, expert science writers are able to give attention to both the content and the rhetorical aspects of writing: novices often become embroiled in the latter and neglect the former.

Klein (1999) described four interpretations of how writing could be used to enhance understanding: spontaneous utterance, forward search, genre-related, and backward search. The spontaneous utterance interpretation assumes that writing shapes thought at the point of formation; that is, the act of converting mental models and ideas into printed representations makes tacit understandings explicit. Authors may use spontaneous utterance to tell what they know, even if other parts of the text involve generating new ideas (Klein, personal communication, 2000). This interpretation is essentially knowledge telling: writers recall ideas from long-term memory and convert them into words, essentially unaltered (Bereiter & Scardamalia, 1987).

The forward search interpretation asserts that writers transform their ideas with ongoing analyses of their texts as they convert mental models and ideas to print and symbolic representations such as figures and graphs without the constraints of a specific goal or purpose. They expand inferences, review idea development, note contradictions, and make appropriate revisions. Even after they have set a top-level rhetorical goal, writers may use forward search to help them mine their existing text for new insights (Klein, personal communication, 2000).

The genre-related interpretation maintains that the use of different function-form frameworks (genre) and knowledge of textual microstructures and macrostructures enables the writer to identify relationships among ideas and clarify understanding of the embedded ideas not apparent in the mental models and ideas held in long-term memory. Klein (1999) maintained "writers used genre structures to organize relationships among elements of text, thereby linking elements of knowledge" (p. 211). Wollman-Bonilla (2000) expressed a generative view of genre, which "portrays genres not as forms to be replicated but rather as forms to be appropriated and reworked in light of text context, function, and the individual writer and intended audience" (p. 38). Evaluation of written text against the structural requirements of the genre may reveal conceptual voids that when addressed improve clarity and internal consistency of the message or identify unrecognized relationships among ideas that when recognized improve conceptual understanding.

The backward search interpretation argues that setting and addressing rhetorical and conceptual goals allows writers to learn through writing as they monitor internal coherence; strength of argument; relationships among claims, evidence, and warrants; and attainment of their goals. Expert writers use backward search to "elaborate rhetorical goals of a writing task to accommodate the interests and knowledge of their audience, the personae they wish to project and the formal characteristics of the required text" (Klein, 1999, p. 243). Geisler (1994) echoed these beliefs. "...[The] expert [must] maintain multiple representations that, even though incommensurate, actually touch and transform each other. An expert who simply replaces everyday discourse with abstract discourse will not be able to manage this transformation" (Geisler, 1994, p. 241). Klein contended that genre writing could be considered a form of backward search in that the author could use a genre, with its associated form, purpose, and elements, to set subgoals to write toward (Klein, personal communication, 2000).

Forward search, genre, and backward search interpretations are forms of knowledge building. Klein suggested that backward search may be considered the top-level strategy, and he contended that writers could bring in other strategies to support it (Klein, personal communication, 2000). Clearly, no single approach is used exclusively in the production of a lengthy text (Anthony, Johnson & Yore, 1997).

Hence the expert writer possesses the ability to write in general, the rhetorical knowledge to write in his or her discipline, and the knowledge of the domain and specific discipline such that he or she may be considered an expert. Yore, et al (2000) described a specific set of abilities of expert writers in and of science.

> Expert science writers have understandings about the nature of science as inquiry; patterns of scientific argument in which evidence, warrants, and claims are clearly linked; the relationship of science, technology, and society; unifying concepts of science; and specific conceptual details. These experts deliberately build representations of the general problem space associated with the communication problems using their mental models of content and their knowledge of written discourse before trying to fine tune the schema to a specific problem (pp. 5-6).

Expert science writers assume solidarity with their audience, even though the audience may not agree with the premises they put forward (Joliffe & Brier, 1988). Indeed, the editing of drafts and the consideration of reviewers' comments provide focused interactions among members of the science research team in which text and content are modified to maximize the clarity, accuracy, and acceptability of the science reported. Yore, Hand, and Florence (2001) stated,

> These debates and negotiations are integral parts of science and writing. Some science writers submit to the reviewers' comments and conform. Other scientists on the leading edge of new or controversial ideas must, in order to be published, augment their claims with intertextuality, compelling evidence, and creative justifications and explanations. (p. 5)

Bereiter and Scardamalia (1991) acknowledged that expert reading and writing involved "effortful problem-solving processes" (p. 190) and thus took time and mental resources, sometimes to the detriment of other work. Yet they argued that the struggle was worthwhile. "Somehow, experts in learned fields must contrive to do all three -- read, write, and do something to write about. ...It should help...to be aware of the synergistic possibilities of carrying out all three activities in ways to extend the limits of one's expertise, thus making it possible for all three to move to higher levels" (p. 191).

Who is an Expert Science Writer?

Yore, Hand, and Florence (2001) and Yore, Hand, and Prain (2000) identified characteristics and beliefs of expert science writers, and some of the findings served as the basis for the study described in this thesis. These researchers used questionnaires and semi-structured interviews to collect data about common attributes, values, beliefs, strategies, and criteria that scientists use when they address different writing tasks and audiences, and to determine if there are associations among scientists' views of science and views of writing.

The scientists in these studies described, implied, and demonstrated the knowledge, metacognition, and emotional dispositions associated with expertise. They also showed expertise in writing for a scientific audience. They used writing to inform and persuade, and to establish themselves in the larger community. The participants noted that they used writing to clarify their ideas. Peer review also helped them improve their writing; in some cases, it was transformational and led them to new understandings of their work.

These scientists believed that science writing had to be judged first by the quality of the science it contained and second by the quality of the writing. Unlike the Yore, et al (2000) scientists, the Yore, et al (2001) scientists expressed an evaluativist view of science in which inquiry directed at specific problems, questions, or issues provided data that were used to describe and explain patterns of events in the natural world. The respondents in the Yore, et al (2001) study tried to align their writing with their beliefs about science and technology; for instance, some would use only passive voice to indicate objectivity. Some expressed an interest in using active voice, thereby acknowledging the presence and influence of the researcher; however, they also were aware of accepted practices in their discourse communities.

The scientists in both studies were cognisant of their audiences. They used jargon as appropriate. Their choice of genre and style also was appropriate to their audiences. Some believed it was better to conform and be published, while others were willing to take the peer reviewers/gatekeepers to task.

The expert science writers described in the Yore et al (2001) study all had supervised graduate students, and many regularly co-author with them. Indeed, many academic publications result from the collaboration of students and faculty, both in the laboratory and at the computer. They also all had been graduate students, and they had varied experiences in writing with their supervisors. Some had received mentoring in writing, and they had essentially learned how to write by reading copious numbers of published research reports and journal papers in their research areas. Others had read a great deal and also had been mentored by their supervisors. None described outstanding experiences; overall, these scientists would have appreciated more mentorship in writing and believed this attention could have provided them with valuable experience and greater perspective on scientific writing.

In summary, these scientists recognized the importance of writing in publishing their results and in receiving research grants and awards, but few explicitly recognized the importance of writing in constructing new science ideas and insights. They further acknowledged the importance of giving their graduate and post-graduate students the most extensive, authentic, and constructive writing experiences possible.

Becoming a Member of an Academic Community

This section of the review is devoted to a discussion of enculturation into an academic discourse community. The meaning and importance of enculturation and mentoring are examined, and application of the concepts of cognitive apprenticeship and legitimate peripheral participation in mentor-protégé relationships are considered. A discussion follows addressing the questions of what students need to know to join a discourse community and where they can gain this knowledge. Finally, several studies of co-authorship are described and discussed.

Enculturation and mentoring in academe

Newton and Newton (1998) referred to the work of Gellatly (1997) and Collins and Ferguson (1993) in their description of enculturation as "a cognitive socialisation in which individuals learn what is an acceptable epistemic form in a particular division of knowledge" (¶ 23). In a study of enculturation of language minority students, Harklau (1998) found that enculturation at university happens at multiple levels, and comprises epistemic stances (ways of knowing) and identities (ways of being). Newton and Newton (1998) pointed to the informal nature of enculturation. "Knowing what counts in a particular discipline is learned through a process of enculturation. Often, it is not a matter of formal instruction, but develops from experience, learning actions, a teacher's example and questions, and evaluations of a learner's performance" (Newton & Newton, 1998, ¶ 21).

Both the cultural and epistemic components of enculturation involve the novice working with an expert in a mentoring relationship. The expert provides domain knowledge through modeling and transmission, experience during activities, and encouragement and insider or tacit knowledge of the disciplinary culture during interpersonal exchange (Perkins, Jay, & Tishman, 1993). Campbell and Campbell (2000) used the terms "more experienced" and "less experienced" to refer to the players in a mentoring situation (¶ 3). They further noted that the success of a mentoring relationship was measured by the less-experienced member's likelihood of achieving his or her goals in the organization. Wilde and Schau (1991) described a mentor in an academic setting as "… an experienced professional who takes personal interest in a graduate student's career and provides guidance and assistance to the student. The student, or mentee, then …[learns] from the mentor and assists him/her in various activities" (p. 167). This *quid pro quo* relationship shall be discussed in terms of co-authorship later in this review.

Polson (1998) emphasized that the relationship between a student and his or her faculty advisor not only defines the quality of the graduate experience, but also surpasses both the Graduate Records Exam (GRE) score and undergraduate grade point average as a predictor of an individual's success in graduate school. Polson stressed that, ideally, advisors become "occupational socializers," fostering not only academic identity, but also a sense of professionalism (¶ 7). Pole (1998) described the supervisory and advisory positions as interactive, growing to meet the needs of the students and to expand the competencies of the students and supervisor.

Jacoby and Gonzales (1991) found that the identities novice and expert most assuredly were not static but could be "…understood as complex and dynamic constitutions of Self and Other brought about by and through interaction over time" (p. 151). The authors studied interactions about writing projects, conference preparations, and other projects in a university physics research team. They discovered that any team member could be "more knowing" or "less knowing" at any point in a discussion, depending on the team member's knowledge with respect to the topic being discussed (p. 152). Jacoby and Gonzales stated

> [R]ather than viewing interactional behavior as the direct, unproblematic outcome of participants' particular hierarchical social identities, we view interaction as the locus wherein social identities are co-constructed, maintained, and modified with consequences for future interactions, even if participants come to the interaction with professionally ranked social identities and a history of past encounters with one another. (p. 174)

Luebes, Fredrickson, Hyon, and Samraj (1998) asserted that their relationships with John Swales featured guidance and true respect: "One of John's strengths as a scholar is his ability to predict the movement of research fields. As his students, we benefited from that strength, as John helped us choose important and interesting topics and draw on relevant research work from a variety of fields" (p. 71). They contended Swales established "... 'power with' relationships with us in the sense that he allowed us to make our own decisions (or at least to think that we did), even if those decisions were often based on his advice. At the same time, the asymmetry of the relationship was evident in his capacity to 'push' us toward long-term issues" (p. 73).

Luebes, et al (1998) described writing as a difficult part of mentoring. Writing generates ideas, but how does one begin writing without ideas? They described how John Swales frequent exhortation to his students "'Just write it!'" (p. 83) impelled them to take risks and join the professional conversation. Luebes, et al also described the benefits of critiquing Swales' papers. "In [allowing us to do this], he helped us build our self-confidence as scholars with valuable contributions to make and he helped us develop critical reading and analytical skills, so crucial to surviving in academia. By treating us in this collegial fashion, as his intellectual peers as well as 'mentorees,' he also eased our transition from students into professional positions as colleagues of other professors" (Luebes, et al, 1998, p. 83).

Ferreira (1998) maintained that the student-mentor relationship is more critical in science than it is in other disciplines because the mentor is often the head of a laboratory, the site of the student's research. Ferreira studied graduate student mentoring in two science departments, looking at the students' perceptions of the level of mentoring, their relationships with their supervisors, and the qualities of an ideal advisor. Not surprisingly, he found that students valued help, expertise, freedom to pursue their own ideas, empathy, trust, respect, and good management of the laboratory situation. The words of one student describe what students look for in a supervisor.

> It's someone who, rather than trying to dominate a student, provides the student with a language and a framework so the student can sort of follow the interests that he/she has already instinctively chosen. …It's someone who is engaged in your work at an intellectual level regardless of how far removed it may seem to his/her own interests. It's someone who wants you to succeed and recognizes that your success is an extension of his/her success. (p. 41)

Boyle and Boice (1998) studied best practices in enculturation of students into graduate programs. They interviewed 66 students and faculty from large, high quality public research universities in the United States, and found that exemplary faculty and, by extension, exemplary departments, were characterized by a commitment to mentorship. These individuals and departments "fostered collegiality among first year graduate students; supported both mentoring and collegial/professorial relationships; and provided 1st year graduate students with a clear sense of the program structure and faculty expectations" (p. 87). Boyle and Boice found mentoring that began in the early days of a graduate's program, for instance, during course work, to be especially valuable. Further, students who had interests and work habits in common with their advisors were more likely to be in nurturing relationships. Finally, exemplary faculty were just that: students emulated those practices that faculty used in support of their own successful careers. Luebes, et al (1998) described their experience "In the final analysis, John's [Swales] greatest influence on our writing may have derived from the attention he gives to his own writing; he is never satisfied with anything less than near perfection" (p. 79).

Cognitive apprenticeship and legitimate peripheral participation

The term apprenticeship is commonly used to refer to activities that surround the master-protégé relationship of crafts, skilled trades, and some professionals. In as much as these actions are associated with critical thinking, knowledge building, and problem solving, they may be considered to constitute a cognitive apprenticeship. Brown, Collins, and Duguid (1989) described the cognitive apprenticeship model as one in which "... mentors (1) ‘model’ by making their tacit knowledge explicit and revealing problem-solving strategies; (2) ‘coach’ by supporting students' attempts to perform new tasks; and then (3) ‘fade,’ after having empowered the students to work independently" (p. 39). The cognitive apprenticeship embeds just-in-time learning in authentic tasks of the disciplinary community with the supportive scaffolding and progressive de-scaffolding of the expert.

Belcher (1994) found the Brown, Collins, and Duguid model lacking in its ability to describe the advisor/student relationship. She contended that this model did not take into account sufficiently variation in advisors' abilities to "scaffold for the apprentice" (p. 24). Further, Belcher maintained that the model neglected to fully consider the community into which the learner sought entry. Finally, Belcher stressed "[the model] has a tendency to view the learner more as a passive recipient rather than as someone who joins a community by consciously becoming an increasingly more active participant in it. An apprentice's willingness to identify with, be changed by, and contribute to the evolution of a community may determine his or her membership in it" (p. 24).

Belcher suggested that the concept of legitimate peripheral participation might be more valuable than the cognitive apprenticeship model in describing the student/advisor relationship. Lave and Wenger (1991) proposed this model of "learning as situated behavior" (p. 29) to describe a newcomer's movement toward full participation in a socio-cultural community.

> In our view, learning is not merely situated in practice -- as if it were some independently reifiable process that just happened to be located somewhere; learning is an integral part of generative social practice in the lived-in world...Legitimate peripheral participation is proposed as a descriptor of engagement in social practice that entails learning as an integral constituent. (p. 35)

Rudolph (1994) discussed the creation of an ideal environment for the establishment of trust and learning between the expert and novice. "Trust is said to exist in an interactive context in which participants co-construct their relationship through verbal and non-verbal indexes in a way that is (a) mutually recognizable, and (b) mutually desirable" (Rudolph, 1994, p. 200). The element of goal sharing is inherent in this relationship, leading Rudolph to conclude "…this work considers apprenticeship to be a socially co-constructed product of the interaction between the novice and the expert. Acquisition of the target Discourse is achieved through the complementary roles of interpreter and interpreted, whereas a bond of trust licenses the participants to carry on the acquisition/apprenticeship process" (pp. 200-201).

Arming students with knowledge of a discipline's inherent cultural and social nuances and tacit understandings helps ease their entry into it. As well, the social construct of trust between supervisor and student is arguably one of the most important elements in establishing constructive working relationships. A student must be culturally and socially as well as scholastically situated in his or her chosen discipline. Thus to engage in cognitive apprenticeship without attending to the centrality of the social, lived-in world is to deny students a comprehensive enculturative experience.

Enculturation and Academic Discourse: Learning What Counts

Language is an essential part of doing and reporting in a disciplined inquiry community. Enculturation must help the novice become acquainted with epistemic stances (ways of knowing) and identities (ways of being) of an academic discourse community. Newton and Newton (1998) pointed to the value of epistemological knowledge of a discipline. "Understanding, valuable in itself, can facilitate the construction of further understanding that, in turn, has its own generative potential....[which] enables effective, independent interaction with the world" (Newton & Newton, 1998, p. 2).

Becher (1989) emphasized that sharing meaning with colleagues in respect to literature and professional language (favoured terms, logical syntax) helps the academic establish his or her own cultural identity. It also serves to keep the academic's subject matter beyond the understanding of those outside his or her discipline. These tactics, though not openly discussed, help maintain the exclusivity of the group of experts. They create an atmosphere in which those on the periphery -- students for example -- become especially desirous of acceptance to the group. Elbow (1991) described the benefits of full membership in an academic circle. "Notice the subtle difference between the discourse of people who are established in the profession and those who are not -- particularly those without tenure. Certain liberties, risks, tones, and stances are taken by established insiders that are not usually taken by the unannealed. Discourse is power" (Elbow, 1991, p. 139).

Becher (1989) contended that admittance to the academic profession not only requires the not only the knowledge to share meanings, but also a "proper measure of loyalty and adherence to norms" (p. 25). Hjørland and Albrechtsen (1995) pointed out that this loyalty might well be expected: If membership has its privileges, it also has it obligations. "Writers in a disciplinary community are part of a discourse tradition and are accountable to the discipline's past, to its shared concerns, and shared knowledge" (Hjorland & Albrechtsen, 1995, p. 407).

Transition to full membership in a discourse community can be made easier for novices if they have the opportunity to work closely with their advisors, established members of the community. Belcher (1994) identified the benefits of novice student writers and expert faculty writers working together. "Collaborative relationships…offer a means of helping students become risk-takers by giving them an insider's appreciation of both the reasons and the rewards for writing up research" (Belcher, 1994, p. 32). Authentic, collaborative writing experiences encourage growth and risk, make the implicit, explicit, and reflect the interactive, constructive nature of writing. Belcher found that advisor/student collaboration on a research paper helped ensure writing success. Undoubtedly part of this success was dependent on the scaffolding provided by the supervisor; however, Belcher found that students who were given responsibility and made their own decisions became confident and able to "negotiate the demands of some of the most advanced literate practices in their fields" (p. 23).

In a study of an undergraduate writing-intensive natural and applied science courses, Chinn and Hilgers (2000) found that instructors who acted as collaborators rather than evaluators chose assignments and instructed in such a way that students became exposed to situations that might occur in collaborative/competitive working communities (p. 1). Students were more satisfied with this approach than they were with a traditional instructor-as-evaluator approach, as they were able to gain first hand experience in professional aspects of writing. Bunch (1995) undertook a study of co-authorship in a mathematics education program. She found "One of the most important things these students came to recognize was the conversational nature of the discourse they were attempting to learn" (p.14). Similar to Chinn and Hilgers (2000), Bunch found "The feedback they received from the professor and from one another served the same purposes as that within the professional community -- response and engagement rather than correction and evaluation" (p. 30).

Dysthe (1999) noted that the process of writing a masters thesis required students to develop a disciplinary identity and situate themselves within a discourse society. Yet they also must be made aware of other ways of writing. Dysthe postulated, "This presupposes an insight which their supervisors and teachers possess as experts, practitioners and writers in the field, but often lack at a conscious or metacognitive level" (p. 3).

Dysthe argued that some knowledge of writing and texts is not discussed in the graduate supervisor/student relationship and thus remains essentially unavailable to the student. Her study of faculty and graduate students in religious studies and administration/organization showed that students had vague ideas about text, that is, either they could not interpret text or lacked the language to discuss it. Thus, the researcher suggested that implicit knowledge about text and language must be made explicit; specifically, teachers or supervisors must recognize the necessity to know and to talk about questions of text and language. Dysthe stressed that students must internalize text norms and develop disciplinary writing competence. Her study found full consensus among students regarding the value of feedback in this regard: it helped them "learn how to write in acceptable ways of the discipline" (p. 9).

Interestingly, Dysthe found that explicit discussion between student and supervisor regarding written work was perceived to have potential negative consequences because "...students' dependency on the authority of the supervisor, students' lack of awareness of choices open to them, students are limited to reproducing the existing forms of academic text, and students' lack of experimentation with new forms" (p. 10).

Face-to-face meetings might have great value for some students if they work to create a closer, more trustful relationship between the students and their advisors. As well, face-to-face meetings may give rise to what Eraut (2000) terms "reactive learning...near-spontaneous and unplanned, the learner is aware of it but the level of intentionality will vary and often be debatable. Its articulation in explicit form could also be difficult without setting aside time for more reflection and thus becoming deliberative" (p. 115). Serendipitous opportunities for learning might occur at any point in student-supervisor meetings, including those that take place during coffee breaks or when chatting in the hall outside the office. Thus the importance of these meetings should not be underestimated.

Prior (1994) focused on the negotiation of a sociology student's prospectus in a graduate seminar by reviewing a response episode and textual revision.

> Students' production of texts and professors' and peer response to those texts are activities central to disciplinary enculturation. These activities provide an opportunity space for socialization into discursive practices, represent a central medium for the display of disciplinarity, and mediate the reproduction

of disciplinary social structure as students achieve relate levels of "success" and "visibility." (p. 483)

According to Prior (1994), these participants followed "sedimented rules" (everyday and specialized discourses, sensemaking practices, and goal structures) within an "emergent event" (feedback and work on a proposal in a seminar) (p. 531). In a somewhat similar study, Prior (1995) considered the nuances of response between a sociology graduate student and her advisor (professor) in the construction of a conference paper. He traced the intermixture of the professor's and the student's words in student's text, and explored the extent to which the professor's words were authoritative or "internally persuasive" (p. 320). Intertextual patterns indicated that the student both incorporated and resisted the professor's written suggestions. The professor's words were internally persuasive to the student; however, the student also influenced the professor. Prior concluded "participation necessarily transforms as well as reproduces social practice" (p. 319). In an effective, constructive supervisor-student relationship, the supervisor does not wish to produce a clone. Neither does the supervisor believe himself or herself to be the single source of all knowledge and learning in the relationship.

Chaopricha (1997) looked at just such a social interaction in her study of three novice writers (doctoral students) in a biochemistry research laboratory. Chapopricha found that "to be able to communicate with other members of the community, biochemistry writers have to understand how biochemists justify their beliefs socially, as well as how knowledge is established and maintained in the discourse community"

(p. 1). Chaopricha looked closely the students' enculturation experiences with "expert" writers (biochemistry professors). She used in-depth interviews, stimulated interviews, and verbal protocols to collect her data. Chaopricha found "coauthoring and conferencing to revise drafts in specialized discourse are efficient methods in supporting novice writers to achieve authority in structuring information for intertextuality and argumentation" (p. 166).

Summary

This literature review describes components of the contemporary science literacy, the complexity of expertise, the attributes of discipline-specific writing, and the enculturation of the novice writer into a discourse community. Contemporary literacy involves more than reading and writing: it comprises the ability to think critically and to take action. This definition is salient to the description of a science-literate person and, specifically, an expert science writer. Expert denotes a high level of critical thinking and metacognition; it also indicates that the individual has the capacity and emotional disposition to take action, and the desire to continuously improve his or her competence. Expert science writers are comfortable within their respective discourse communities; they use their knowledge of genre and audience to construct new science ideas and insights. Expert science writers in academia further recognize their responsibility as mentors of graduate and post-graduate students. Exemplars of science literacy, these research supervisors work with novice scientists to help them become expert writers in and of science. The remainder of this thesis details an investigation of this process as it unfolds during co-authorship experiences of two expert science writers and their graduate and post-graduate students.

CHAPTER 3

METHODOLOGY

Introduction

A case study approach was used in this exploration of enculturation involving research supervisor/graduate student co-authorship in two science departments at a western Canadian university. Yin (1994) suggested that a case study comprises five especially important components: 1) a study's questions; 2) its propositions 3) its units of analysis; 4) the logical linkages between the evidence and the propositions, and 5) the criteria for interpreting the findings. This chapter details these components and includes a description of the instruments and procedures used to collect data, procedures used to summarize and validate the data, and the interpretive framework. A discussion of controlling the researcher's biases concludes the chapter.

Research Strategy

A case study is an exploration of a "bounded system," a case or multiple cases over time through detailed, in-depth data collection involving multiple sources of information (Cresswell, 1998, p. 61). Yin (1994) contended that case study inquiry

> …copes with the technically distinctive situation in which there will be many more variables of interest than data points, and as one result relies on multiple sources of evidence, with data needing to converge in a triangulating fashion, and as another result benefits from prior development of theoretical propositions to guide data collection and analysis. (p. 13)

A case study differs from other forms of interpretive research in that it recognizes the work done by others and utilizes other works to plan, improve, and interpret the current research.

This case study developed interpretive frames based on the research literature. The frames use theoretical assumptions, propositions, and evidentiary linkages to study enculturation, development of expertise, and acceptance into a scientific discourse community during co-authoring. Text-based, interview-based, and meeting-based information were collected in two science research groups to explore these propositions.

Case studies may be single or multiple. Multiple-case studies, such as the one reported in this thesis, may be considered a collective case study. Stake (1994) states, "…researchers may study a number of cases jointly in order to inquire into a phenomenon, population, or general condition. We might call this a collective case study. It is not the study of a collective but an instrumental study extended to several cases" (p. 237). Multiple case studies utilizing common questions, procedures, data sources, propositions, and analysis principles contribute to the generalizability of the results.

Validation of data is a central concern in case studies. Stake (1994) suggested misinterpretation of data could be lessened greatly by using triangulation, which comprises redundancy of data gathering and procedural challenges to explanations. Stake stated, "Triangulation has been generally considered a process of using multiple perceptions to clarify meaning, verifying the repeatability of an observation or interpretation" (p. 241). Lincoln and Guba (1985) referred to the necessity of triangulation: "As the study unfolds and particular pieces of information come to light, steps should be taken to validate each against at least one other source …and/or a second method…. No single item of information (unless coming from an elite and unimpeachable source) should ever be given serious consideration unless it can be triangulated" (p. 283). Triangulation also ensures that a breadth of information has been documented and considered on any specific issue. Data in this study were derived from questionnaires, and student/research supervisor conferences, and interviews.

A purposeful sample was selected for this multiple case study. The research supervisor participants were chosen based on their documented characteristics (Yore, Hand & Florence, 2001). The two research supervisors chosen for the study wrote well, were well published, and were recognized as experts in their specific scientific fields. They enjoyed mentoring and were enthusiastic about teaching their students about writing for publication. The student participants were chosen opportunistically, that is, their participation was based on their involvement in co-authorship activities with their supervisors at the time the study was undertaken.

The research supervisors/supervisors and their students were not necessarily representative of the greater population in science, in the specific disciplines, or in the host departments, but they offered the greatest opportunity to observe an exemplary, constructive co-authorship process. Stake (1994) maintained that indeed the most fruitful cases are not necessarily the most typical. "The researcher examines various interests in the phenomenon, selecting a case of some typicality, but leaning toward those cases that seem to offer some opportunity to learn" (Stake, 1994, p. 243).

Yin (1994) considered a somewhat different method of selecting cases. "Each case must be carefully selected so that it either (a) predicts similar results (a literal replication) or (b) produces contrasting results but for predictable reasons (a theoretical replication)" (p. 46). The cases selected in this thesis work are similar for the reasons stated in the previous paragraph, and they are different because they were chosen from different university departments and different disciplinary cultures. Thus one might expect contrasting results to be somewhat predictable. In addition to providing some contrast, the studies were expected to provide a close link to established literature in biochemistry co-authorship activities (Chapopricha, 1987), extended linkages to a new field (atmospherics physics), and insight into the hybrid interdisciplinary science domains.

Stake (1994) stated, "The purpose of case study is not to represent the world, but to represent the case" (p. 245). Miles and Huberman (1994) described the quantitative-qualitative dichotomy with respect to sampling. "Quantitative researchers often think randomly, statistically, and in terms of context-stripped case selections. Qualitative researchers must characteristically think purposively and conceptually about sampling…" (Miles & Huberman, 1994, p. 441). Yin (1994) explained the difference between generalization in case study research and generalization in empirical sampling research.

> …case studies, like experiments, are generalizable to theoretical propositions and not to populations or universes. In this sense, the case study, like the experiment, does not represent a 'sample,' and the investigator's goal is to

> expand and generalize theories (analytic generalization) and not to enumerate frequencies (statistical generalization). (p. 10)

The case studies described in this thesis were not undertaken to make predictions about the experiences of all research supervisor-graduate student or post-graduate student co-authorship teams. Rather it was carried out to gain an "understanding of the conditions under which a particular finding appears and operates: how, where, when, and why…" (Miles & Huberman, 1994, p. 441). This multiple-case study of five advisor-student teams aims to explore co-authorship as an enculturative act, and to ascertain if the process of co-authorship enhances the student participants' science writing proficiency.

Firestone (1993) discussed analytic generalization and case-to-case transfer in case study research. The former is "facilitated by specifying conditions under which a study is done and their relevance to multiple theories. That knowledge is used to create controls, quasi-experimental designs, or replications that strengthen generalization" (p. 18). In case to case transfer, generalizability from one case to another depends on the readers ability to "assess the match between the situation studied and their own, especially since their situations might be quite different" (p. 18). Firestone contended that this identification could be accomplished if the writer used rich, thick descriptions to detail the case study findings. He further maintained that the reader was obliged to "use his other tacit understanding of the case to bridge the gap between the written case and the application setting" (p. 18). Indeed, the results of this case study are not generalized; however, this thesis was developed to be generalizable to the reader. The reader must use his or her knowledge of similar experiences to help understand the findings, and perhaps to identify experiences and activities in the study that could be investigated further or attempted in his or her own life.

Framework for this Multiple Case Study

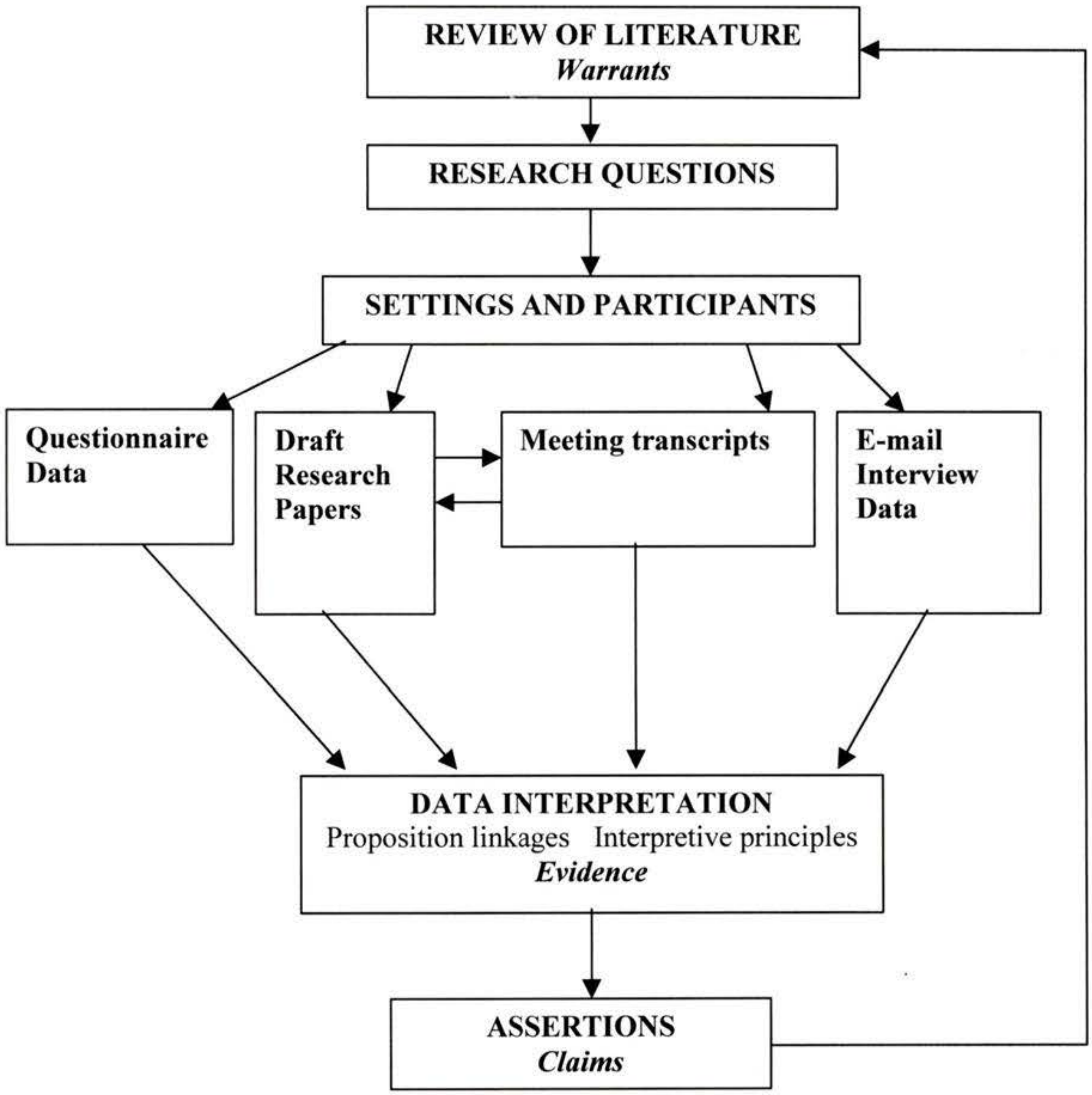
This section of the chapter comprises information about the (1) setting, (2) participants, (3) procedures and instruments used to collect data, (4) an interpretive framework of assumptions, propositions, and evidence, and (5) efforts made to control investigator bias. This information is preceded by a conceptual framework (Figure 1), which represents the organization that was followed in the collection and interpretation of data/evidence, and the comparison of assertions/claims with warrants/results of the literature search.

Research Questions

The research questions under study are:

1. What are the activities and processes inherent in the co-authorship of research documents?
2. How do the graduate student's or post-graduate student's and the research supervisor's beliefs about writing agree/disagree?
3. Does co-authorship help the student become an expert science writer?

Figure 1. Conceptual Framework for Methodology



Setting

The bounded system or cases were the respective graduate or post-graduate student-research supervisor relationships, which centered on co-authorship of academic papers during the late winter and spring of 2001. The physical setting for this research was the Department of Biochemistry and Microbiology, University of Victoria and the School of Earth and Ocean Sciences, University of Victoria. The cultural setting was the disciplinary community of the participant; it comprised university level research and teaching in microbiology and earth and ocean sciences, respectively. The cultural setting also included the discourse community into which the students hoped to be inculcated through the co-authorship. The two discourse communities (the biochemistry of parasitic diseases and the atmospheric physics of climate dynamics, respectively) were represented by the specific genre of the paper and the targeted research journal.

Participants

A purposeful sample of five advisor-student co-authorship teams was chosen. Each team worked on a different journal paper:

- Biochemistry Team #1 (BT#1): the biochemistry research supervisor and one of his Masters' students
- Atmospheric Team #1 (AT#1): the atmospheric physics research supervisor and two of his post-doctoral students
- Atmospheric Team #2 (AT#2): the atmospheric physics research supervisors and one of his PhD students

- Atmospheric Team #3 (AT#3): the atmospheric physics research supervisor and one of his post-doctoral fellows.
- Atmospheric Team #4 (AT#4): the atmospheric physics research supervisor, one of his post-doctoral fellows, and one of his PhD students.

The two research supervisors were expert writers and renowned scientists with a large number of publications in their respective research areas. During the Yore, Hand, and Florence (2001) study "Scientists' Views of Science, Models of Writing, and Science Writing Practices," these two research supervisors had indicated that they enjoyed writing and that they regularly coauthored documents with their graduate students. Hence their participation was requested by this researcher, and they kindly agreed to take part in this study.

Even though the student participants had previously collaborated on journal papers, overall they were less proficient and experienced science writers than were their supervisors. They also were not fully accepted members of their chosen disciplines. Thus the students were considered novice science writers for the purposes of this study. The student participants were identified and asked to participate by the research supervisors. They were chosen based on their participation in current co-authorship experiences with their supervisors, and thus could be considered to comprise an opportunistic sample. The student participants were enrolled in a Master programs (1 female), a PhD program (2 males), and post-doctoral fellowship studies (1 female and 2 males). It is noteworthy that the post-doctoral fellows all were educated at European universities and did not consider English their first language.

They were all proficient English speakers, however, and, in general, their writing could be considered as least as good as that of the average Canadian-born graduate student.

Each participant was asked to sign a consent form. The form described the purposed of the research, the rights and requirements of the participants, and a promise of confidentiality (Appendix A). All participants were asked to select pseudonyms for themselves, and these names are used in this thesis to protect the participants' anonymity. They also were asked to review the findings of the study to verify that their statements and actions had not been misinterpreted.

Biochemistry Team #1 (BT#1)

Title of co-authored publication: Protein microchemical and mass spectrometric identification of an endosymbiont GroEL as the major protein expressed in the midgut of the tsetse fly *Glossina morsitans morsitans*.

Cotton (a pseudonym) is a research supervisor in biochemistry, specializing in immunochemistry and biochemistry of parasitic diseases, immunology of membrane antigens, and immunodiagnosis of disease. He notes that the main focus of research in his laboratory is on the cell surface molecules of protozoan parasites, primarily African trypanosomes. Cotton has been a faculty member at the University of Victoria for more than 20 years. He publishes regularly in molecular biology and molecular parasitology journals, including Molecular and Biochemical Parasitology and Parasitology Today. Cotton has received a great deal of positive attention in the popular press for his work on African sleeping sickness, and he has travelled to Africa on several occasions to conduct research and meet with colleagues.

Rayne (a pseudonym) is a Masters student in biochemistry. She received a BSc in biology at another Canadian university, with a speciality in parasitology, microbiology, and marine biology. Rayne joined Cotton's laboratory in 1999, and her area of study is parasitology, specifically interactions between African trypanosomes and the tsetse fly.

Atmospheric Physics Team #1 (AT#1)

Title of co-authored publication: "Forcing of the Deep Ocean Circulation in Simulations of the Last Glacial Maximum"

Alistair, Karin, and Alexander: Alistair (a pseudonym) is a research supervisor in the School of Earth and Ocean Sciences, with an interest in the role of the oceans in climate change/variability; ocean/climate modeling; paleoclimate; physical oceanography; and geophysical fluid dynamics. Alistair describes the research in this laboratory as focusing upon the large-scale ocean circulation and the role of the oceans in climate, with a special emphasis upon three-dimensional numerical modeling. Alistair has been on faculty at the University of Victoria for nine years; he was awarded a Canada Research Chair and elected a fellow of the Royal Society of Canada in 2001. He publishes regularly in a number of climate and geophysical journals, and on occasion in more widely circulated journals such as Nature and Science. Alistair's research also has been covered extensively in the popular press, and he has written several op-ed pieces.

Karin (a pseudonym) is a post-doctoral fellow specializing in physical oceanography and climatology. After completing a doctorate in physics in Europe, Karin came to the University of Victoria to study with Alistair in 2000. Her principle area of study is climate modeling and ocean circulation changes.

Alexander (a pseudonym) is a post-doctoral fellow in climatology. He received his PhD in Europe in climate physics. Alexander joined Alistair's laboratory in 2000, and his principle area of study is numerical modeling of the atmosphere-ocean system.

Atmospheric Team #2 (AT#2)

Title of co-authored paper: "Trends in the Diurnal Temperature Range in the CCCma Coupled Model"

Alistair and Daniel: Daniel (a pseudonym) is a PhD student in climatology. He comes to Alistair's laboratory having received a BSc (honours) in physics and math and an MSc in climatology from the University of Victoria. Daniel worked as a research assistant and teaching assistant during his undergraduate program. His dissertation focuses on changes in the global mean surface area temperature.

Atmospheric Team #3 (AT#3)

Title of co-authored paper: "Importance of Wind-Driven Sea Ice Motion for the Formation of Antarctic Intermediate Water in a Global Climate Model"

Alistair and Victor: Victor (a pseudonym) is a research associate specializing in physical oceanography. He received a PhD at a European university and came to Canada in 1999 as a visiting scientist at the Institute of Ocean Sciences. Victor joined Alistair's research group in 2000. His principle area of study is sea ice modeling and coupled ocean-ice-snow-atmosphere modeling.

Atmospheric Team #4 (AT#4)

Title of co-authored paper: "Instability of Glacial Climate in an Earth System Climate Model"

Alistair, Alexander, and Ryo: Ryo (a pseudonym) is a PhD student who comes to Alistair's laboratory with a Masters of Engineering (Mineral Resources) from an Asian university. Ryo's current area of research is paleoclimate modeling with an emphasis on the climate changes and variabilities during the last glacial cycle (125,000 - 6,000 years ago).

Procedure

Participants were given a questionnaire to ascertain their respective background experience in science and their beliefs about science writing (Appendices B &C). Research supervisor participants had answered these questions in a written questionnaire in the Yore, Hand, and Florence (2001) study. Participants were then followed through the drafting process of a research report manuscript. Each time a research supervisor and a student or students met formally to discuss the process, they were observed and audio-taped with their permission. This experience provided valuable insight into the co-authoring process and demonstrated components of the research supervisor-student relationships. Chaopricha (1997) described the value of conference protocols. "While writers' text moves are important to look at, a great deal of the constructive work of the composing process is done outside of the text itself – in interpreting the rhetorical situation, locating and evaluating relevant data and other resources, and creating inferences that connect data to a set of claims" (Chaopricha, 1997, p. 56).

Field notes and reflective notes (Cresswell, 1998) were taken by the researcher at each meeting. Field notes included general descriptions of what went on in the meeting. Reflective notes included questions by the researcher to herself about the meaning of certain processes, as well as general observations about the participant's affect, body language, and other non-verbal indicators.

Edited drafts, including research supervisors' suggestions and students' responses, were collected. During their writing or soon thereafter, students were given part two of the questionnaire (Appendix F) to establish the methods they used when they wrote, for example, did they use outlines, did they edit and revise, and so on. Research supervisor participants had answered these questions in a written survey in the Yore, Hand, and Florence (2001) study. Finally, the participants were asked to reflect on their co-authoring experiences and to suggest any other activities that would aid students (research supervisors' response) or themselves (students' response) in becoming proficient science writers (Appendix G).

Instruments

Three instruments were used to collect data from the five research supervisor-student teams. Data from questionnaires, conferences, manuscripts, and interviews were collected opportunistically from January 2001 to June 2001.

Questionnaire

All participants were given a questionnaire to collect information about their backgrounds and the types of writing they had done. The research-advisor participants were given the questionnaire in the summer of 2000 (Yore, Hand & Florence, 2001). This questionnaire (Appendix B) was based on a review of the literature, informal discussions with practicing scientists, and previous research (Yore, et al., 2000). The 21-item questionnaire was followed by an interview (Appendix D, Cotton; Appendix E, Alistair) to clarify and expand on selected points. The questionnaire and follow up interview addressed five major foci:

- Focus 1 determined the type of writing engaged in by scientists, their awareness of audience, and the audience's influence on their writing.
- Focus 2 explored the criteria that scientists used to judge their own and other scientists' writing.
- Focus 3 explored the metacognition and strategies scientists applied to complete their writing tasks.
- Focus 4 explored the relationship between writing and constructing knowledge.
- Focus 5 explored the scientists' beliefs about the nature of science.

The student participants were given questionnaires (Appendices C and F), which were modeled after the research-supervisor questionnaire. The student questionnaire included most of the questions in the research-supervisor questionnaire and follow-up interview, and a few questions specific to the students' experiences. The foci addressed by these instruments were the same as those listed above.

Student-Research supervisor conferences

Draft manuscripts, with revisions, and outlines were collected from the research supervisor-student teams. All formal team conferences were attended and audio-taped. Informal meetings of participants and the resulting conversations that occurred in the laboratory were not captured. The following team meetings were fully documented:

BT#1: January 10, 2001; April 4, 2001; AP#1: February 2, 2001; AP#2: February 20, 2001, April 6, 2001; AP#3: May 9, 2001; AP#4: June 8, 2001

Field notes were taken during the conferences as the participants proposed revision to the text, timelines, and possible publishing venues. New ideas that sprang from the discussions were noted. Informal discussions with students took place on occasion and afforded the opportunity to learn more about their backgrounds, their research interests, and their academic aspirations.

Interviews

The research supervisor participants were interviewed during the Yore, Hand, and Florence (2001) study (Appendices D and E). The interviews were custom designed for each respondent to reflect a preliminary analysis of their questionnaire responses and ranged in length from 30-60 minutes. Each research supervisor was asked to elaborate on his responses on the questionnaire and to select or describe his understanding of the nature of science. Some of their responses were used as background information for this study, especially those that pertained to their writing experiences in graduate school and what they expected and encouraged in their own graduate students writing experiences.

A short culminating interview was done via e-mail with the research supervisors, graduate students, and post-graduate students to ascertain their final thoughts on the co-authorship experience (Appendix G). For instance, students were asked whether the experience influenced their writing. Responses from one non-native English speaking student and one native English speaking student can be found in Appendix H. Research supervisors were asked whether they saw changes in their students' writing, critical thinking, and metacognition during the co-authoring process. Both students and research supervisors were asked if they saw evidence of knowledge building or conceptual change in members of the co-authoring teams. They also were asked to describe their roles in the process, and whether being observed affected their interactions.

Data Interpretation

Data from each questionnaire were entered in a word processing file. Questions were then grouped together (e.g. all of question one, question two, and so on). Transcripts were made of each audio-taped meeting. Drafts of research papers were compared and authors' reactions, margin notes, and revisions noted. Final e-mail questionnaires were transferred to word processing files.

A framework for data interpretation was developed using the following propositional linkages and interpretive principles or themes abstracted from the literature review of science literacy, expertise, enculturation, science writing, and group dynamics (Appendix I). Each interpretive frame comprises a research literature-based assumption, a proposition of what is likely to be observed, and several interpretive principles believed to be connected to the anticipated evidence. The interpretive frame headings are followed by the numbers of the research questions (RQ) that the proposition addresses. Word files and draft manuscripts were searched manually for the presence or absence of supporting evidence in the form of specific words or phrases related to the seven propositions. Unexpected findings were documented for further exploration.

Interpretive Frame#1: Science Literacy (RQ #1, #2)

Assumption: In order to do science, scientists must have the cognitive abilities and emotional dispositions to construct science understandings. The personal and social qualities necessary to do science are referred to as habits of mind, and they include curiosity, skepticism, and openness. These traits are also associated with critical thinking, which is manifest in mindfulness, investment of mental effort, and willingness to take intellectual risks.

Proposition: Members of a research laboratory, and specifically members of these co-authorship teams, would be expected to demonstrate habits of mind conducive to doing science, and to writing, revising, and submitting scientific papers for publication.

Interpretive principles: curiosity, skepticism, openness, mindfulness, mental effort, and risk taking

Interpretive Frame #2: Nature of Science (RQ #1, #2)

Assumption: The big ideas of science often are manifest in beliefs about the nature, structure, and key knowledge claims of science. However, there is no universally agreed upon view about the nature of science. Conflicting philosophies about the nature of science have been dealt with by positing three viewpoints: science as induction -- just give me the facts; science as falsification -- just give me the imperfect facts; and science as relativistic -- my facts are as good as yours (Lederman, 2001).

Proposition: Each co-author is likely to have his or her unique view about the nature of science. These ontological and epistemological beliefs are expected to affect how co-authors conduct their research, how they craft an argument, and how they use language to express their findings.

Interpretive principles: positivistic view of nature of science (traditional, absolutist); evaluativist view of nature of science (modern, interactive-constructivist); and relativist view of nature of science (post-modern, radical constructivist view).

Interpretive Frame #3: Role of Writing in Science (RQ #1, #2)

Assumption: Writing is an essential part of doing science. Speaking, reading, and writing are constitutive as well as communicative and transmitive parts of science (Norris & Phillips, 2001). Hence, those who aspire to expertise in any given scientific field must have the ability to transform their findings into text. They must then expose the texts to their own scrutiny and that of their peers, and subsequently be able to use personal reflections and peer criticism to refine and reconstruct their ideas.

Proposition: Co-authors are expected to realize and respect the essential place of writing in their scientific endeavours and careers. They should be knowledgeable about the language of their disciplines, accepted genres, the role of citation, the use of hedging, the importance of audience awareness, and the value and restrictions of peer review.

Interpretive principles: disciplinary language; genre/genre knowledge; intertextuality and citation; hedging; audience; and peer review.

Interpretive Frame #4: Scientific Expertise (RQ #1, #2)

Assumption: Growth in expert communities takes the form of progressive problem solving determined by the pressing issues of the discipline and increased competence. Experts, as life-long learners, will continuously use their unique talents to tackle new problems and acquire new competencies. Expertise features metacognition and self-regulation, as well as general domain and specialty knowledge, abilities, and dispositions.

Proposition: As highly regarded scientists in their respective fields, the research supervisors in this study are expected to exhibit expert characteristics. They may be expected to display these characteristics in their conduct and in their work (laboratory and written).

Interpretive principles: progressive learning, assimilation, knowledge building schema, self-regulation, metacognition, self-confidence, healthy intellectual tension, judgment, and risk taking.

Interpretive Frame #5: Expert Science Writer (RQ #1, #2)

Assumption: The expert writer possesses the ability to write in general, the rhetorical knowledge to write in his or her discipline, and the knowledge of the domain and specific discipline such that he or she may be considered an expert. Expert writers are transformers of knowledge, using metacognition to compose, to represent mental models and ideas, and to resolve contextual discourse problems. Expert writers of science emphasize good science first and good writing second.

Proposition: Co-authors in this study are expected to be able to write and to have discourse knowledge and domain knowledge and metacognition appropriate to their respective disciplines. Their writing should help them transform their knowledge, and this should be evidenced in choosing a genre, setting rhetorical goals, selecting language, resolving differences, addressing reactions, and reviewing and revising.

Interpretive principles: discourse knowledge, domain knowledge, metacognition, persuasion, revision, rhetorical goals, genre selection, and journal selection.

Interpretive Frame #6: Enculturation into the Scientific Research Community (RQ #2, #3)

Assumption: Enculturation into a discipline entails learning its epistemology, which is manifest in its language. Language has shared meanings, which form the basis of a discourse community. Mentors implicitly and explicitly model the community's language norms, conventions, and traditions, and transmit knowledge of the discourse community to novices. Members of a discourse community sometimes use jargon and slang to exclude outsiders, but most often jargon is used to increase the community's efficiency or to label or connect ideas. Students learn to write in their disciplines by their involvement in authentic activities such as co-authoring a research paper.

Proposition: Research supervisor team members will likely inform students about the nature of their respective discourse communities by modeling language selection and use during the co-authorship process. Students will use their co-authorship experiences to help them become more proficient writers in and of science.

Interpretive principles: "just-in-time" teaching, shared meaning, language use/jargon, authentic enculturative activities, and adherence to discourse community norms.

Interpretive Frame #7: Dynamics of Collaborative Groups – Co-authoring Teams (RQ #2, #3)

Assumption: Students are expected to assume certain roles within the research team; however, these roles change on occasion and over time. They also are expected to show loyalty and respect for the discipline's culture, history, and status. All team members are expected to respect one another and to work to build mutual trust, while advocating different interpretations and participating in scientific debate (academic civility). Even in the most egalitarian laboratories, the team member with the highest academic status or the grant authority holds most if not all of the power.

Proposition: Role reversal may be apparent, depending on the topic being discussed. All team members are expected to show loyalty for their discipline, and trust in and respect for other team members. Power differentials based on academic standing are likely to be apparent, but the collaborative climate of co-authoring tends to dilute many of the traditional power moves.

Interpretive principles: disciplinary culture, academic civility, role reversal, loyalty, respect, trust, power, and academic status.

Awareness of Prior Conceptions and Possible Bias

Disciplined inquires require that a well-prepared researcher guards against uncontrolled biases that could negatively affect data collection, distort evidence, and influence results. Case studies require doubled effort to ensure evidence is rigorously collected, well documented, and recorded for external consideration. Furthermore, unexpected findings need to be documented for further exploration.

The first step in controlling bias is recognizing that all researchers carry with them prior knowledge and expectations. Bachor (in progress) defined the term head-notes "to refer to the information that researchers have in their heads that inform how they view and interpret any problem/issue and the accompanying research evidence" (p. TBA). Head-notes or "notes in the head…[take the form of] so-called hunches, insights, and very provisional formulations of hypotheses" (Strauss, 1987, p. 12). This study was started with several head-notes about collaborative writing and research writing in a university setting, plus substantial researcher experience working with research supervisors, post-doctoral fellows, and graduate students in laboratory and field research. This researcher recognized the concurrent experience of thesis research and preparation and was mindful of her head-notes and cognizant of how they influenced the collection and interpretation of data. For instance, during the student-advisor meetings, the researcher attempted to distance herself from the participant interaction and discussion of the research papers, attempting rather to watch and listen closely to the collaborative process as it unfolded. The influence of the researchers' presence was explored in the culminating interview with co-authors. During the interpretive stage, the researcher considered the entire data set, as opposed to seeking out and selecting those statements or portions of text that supported her propositions. Bachor (in progress) described the importance of making the selection process clear:

> The dilemma in reading many case studies is that it is not clear how the portrayed evidence was selected for inclusion in the case report. It is possible to select evidence to correspond with claims that the author wishes to advance, as may be the case in the head-note evidence-incorporation approach to case studies. Alternatively, the author can choose to present representative illustrations of the obtained information. In either approach, to increase the believability of the case study the underlying assumptions must be revealed. (pp. TBA).

The researcher also guarded against bias and misunderstanding by using triangulation across external investigators, informants, sources, and methods (Lincoln & Guba, 1985). While not an actual investigator in this instance, the research supervisor overseeing this thesis work had a great deal of knowledge in the theoretical and actual activities inherent to co-authoring. Hence, frequent meetings with this individual provided the researcher opportunity for discussion and verification. As well, information obtained from the participants was verified with them to "ensure that the informants' intent [was] captured in the collected evidence" (Bachor, in progress, p. TBA). Finally, as discussed earlier in this chapter, data were obtained through multiple sources and methods: questionnaires, interviews, observations of meetings, and reviews of draft manuscripts.

CHAPTER 4

RESULTS AND DISCUSSION

Introduction

The first section of this chapter provides a diagrammatic representation of the general activities and processes that locate the co-authoring activities within the scientific publication system, descriptions of the two research laboratories, and overviews of the general publishing processes each laboratory follows. Using the interpretive frames outlined in chapter three, the second section draws together data from questionnaires, draft manuscripts, referees comments concerning submitted manuscripts, team meetings, and e-mail interviews relating to: (1) the writing processes team members' report to use and those they actually use in practice; and (2) the beliefs team members' report to hold, and those they actually exhibit, concerning science literacy, the nature of science, the role of writing in science, scientific expertise, the expert science writer, enculturation into the scientific research community, and the collaborative dynamics of the co-authoring teams. The third section of this chapter outlines the beliefs team members report to hold about the role co-authorship in helping them become expert science writers. Data for this section come from the final e-mail interviews. The fourth section offers interpretations of the findings in the previous three sections of this chapter, and posits assertions that address the study's three research questions.

Activities and Processes in the Scientific Publication System

Science laboratories typically follow common processes in the preparation and submission of manuscripts for publication in scholarly journals. Berkenkotter and Huckin (1995) described this process as a "discursive network of texts and actors that constitute the scientific publication system…[comprising] the textual activities through which the research resources of the laboratory represented in the manuscripts are converted into the finished product of validated knowledge claims" (p. 62). This publication system includes research grant preparation and review; however, this study focuses only on the laboratory research and preparation of manuscripts for submission to referred journals (Figure 2).

The discursive network involves a series of returns to the laboratory for additional data, to the statistical system for new analyses, and to the composition stage for clarification of ideas and refinement of text. The three main stages in the life of the publication represented in Figure 2 are: (1) pre-submission (light grey shading) (2) submission, review, and re-submission (medium grey shading), and (3) acceptance and publication (dotted background). It is noteworthy that although the rejected manuscript appears to be cast aside in this instance, it is not always abandoned, since most authors attempt to find another suitable audience and journal for such manuscripts.

Description of the Research Laboratories

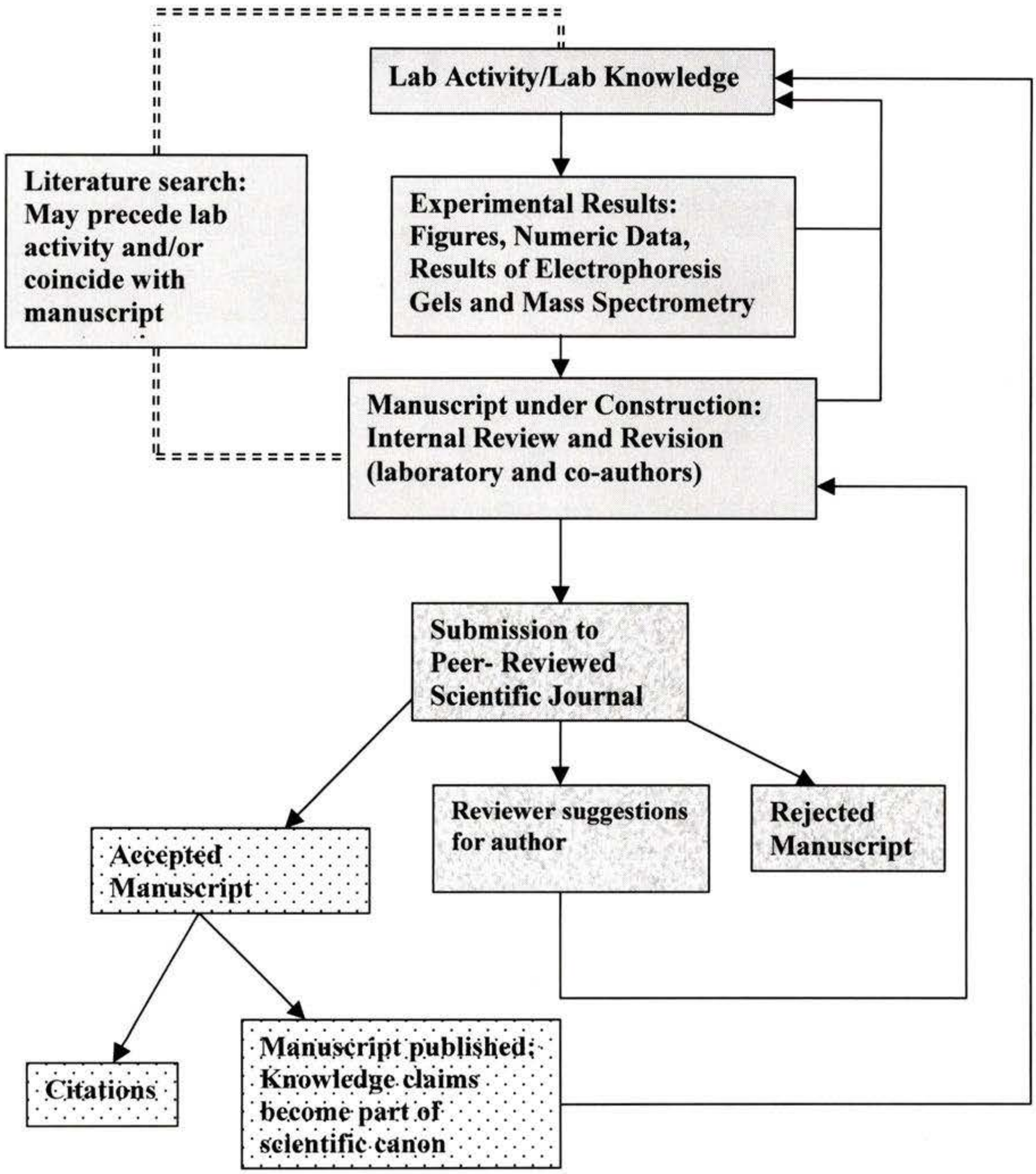
Cotton's Laboratory

Cotton's biochemistry laboratory focuses on the microbiology of tropical diseases, primarily the cell surface molecules of the parasites (trypanosomes) responsible for African sleeping sickness. Tsetse flies infected with the parasites can transmit the disease to livestock and to humans. The parasite is especially hardy because it can alter its surface molecules, a process called antigenic variation, and thus is able to avoid the host's immune system. Although it has received less attention than AIDS, sleeping sickness affects over 500,000 people in Africa (Pearson, personal communication, 2000). It is a horrific disease, with no known cure and a very painful and expensive treatment – patients are injected with Melarsoprol, a caustic mixture of arsenic and glycol (also found in antifreeze), which burns the patient's flesh around the injection site. Many patients die, even with treatment.

Cotton became interested in sleeping sickness in 1977 when after completing his post-doctoral studies, he accepted a research position at the International Livestock Research Institute in Nairobi, Kenya. He has studied the disease since that time, focusing on parasite-host-vector relationships. Cotton has become a world expert on sleeping sickness. Working with colleagues in Canada and Africa, he has successfully used information about several trypanosome antigens to devise diagnostic tests for the disease. He hopes his team's research will ultimately lead to development of a sleeping sickness vaccine.

Cotton's laboratory is by no means extravagant or expansive, but it is a hotbed of activity. At any one time, three or more graduate students and two technicians are working at the benches setting up experiments, compiling and analyzing data, sending information to or receiving information from collaborating laboratories via electronic mail, or searching indexes or websites on the internet. Cotton describes the laboratory's internet use "We access a number of databases [including] DNA and protein databases. …There are also programs available on the internet that allow us to do certain [analyses] of different molecules. As well, I'm in contact with five or six labs worldwide on a daily basis."

Figure 2. From laboratory to peer-reviewed journal (Adapted from Berkenkotter & Huckin, 1995)



A keen observer and excellent teacher, Cotton can most often be found in the laboratory, working with students or questioning them about their work, or in his office, choreographing upcoming projects. Students and technicians also discuss their work with one another. The Department of Microbiology and Biochemistry holds poster sessions every fall and the students have an opportunity to present their work. The departmental graduate students organize journal-club meetings every second week where work and experimental problems or issues are presented and discussed. Cotton's students also do seminars from time to time in Cotton's laboratory, where they have the chance to present their work and question one another, discuss a recent journal article, or just brainstorm about new ideas and possibilities. According to Rayne, Cotton "makes it a point to make us read any type of noteworthy publication that has anything loosely to do with science, investing, and, of course, AFRICA!" Cotton and his students have developed close bonds and a great deal of mutual respect. They try to meet frequently outside the laboratory setting to have a refreshment break and talk about their current research projects.

The case of Cotton and Rayne centers mainly on the early stages of co-authorship, specifically on the discussion about and drafting of outlines for a paper on the identification of major proteins in the midgut of the tsetse fly *Glossina morsitans morsitans*. The pre-writing discussion between Cotton and Rayne helped them identify the target idea and established the need for additional data and new laboratory procedures. They have chosen to submit the manuscript to Insect Biochemistry and Molecular Biology. The entire case study focused on the pre-submission stage of the publication process (Figure 2).

Alistair's Laboratory

The word 'laboratory' usually brings to mind benches, sinks, and fume hoods. Alistair's laboratory consists of a group of offices that feature powerful computers, laser printers, and sophisticated software. Alistair and his research team work in climate modeling, primarily three-dimensional numerical modeling. The models they produce simulate climate changes over time, and the group uses the models to investigate whether the changes have occurred naturally or have resulted from human activity. One model known as the Earth System Climate Model or the UVic coupled model features ocean, sea ice, and land ice components, and has become one of the standard models used in climate research worldwide.

Alistair is a very busy man. As well as supervising six research associates and ten graduate students, this world expert in climate change teaches in the undergraduate and graduate earth and ocean sciences programs, and is an active member of several national and international research committees and working groups. Alistair is much sought after by the national and international media, both for his knowledge and for his patience and willingness to discuss climate change in plain language.

A gregarious and energetic man, Alistair works closely with his research team on a regular basis. His students and staff respect him a great deal, and the respect is mutual. In a recent interview addressing his appointment as the University of Victoria's first Canada Research Chair, Alistair described his relief at having job security for his research assistant and computer systems manager, noting they were "the glue that holds the group together." It is clear he values each member of his team for his or her particular knowledge, skills, and emotional dispositions. Alistair's team members have very strong bonds of trust and respect among them.

The cases of Alistair, Karin, and Alexander (AT#1: deep ocean circulation); Alistair and Daniel (AT#2: diurnal temperature range); Alistair and Victor (AT#3: sea ice motion); and Alistair, Alexander, and Ryo (AT#4: climate variability and modeling) all represent slightly different stages of co-authorship (Figure 2). Cases AT#1 and AT#4 are similar enough to be described together, focusing on the final stages of writing just prior to submission: discussions of specific wording, style, and journal selection feature prominently in these cases. Case AT#2 focuses on the planning stage: Discussion of organizing the data, including which figures to include, style, and target journal predominates. Case AT#3 comprises the entire process, from planning to re-submission of the manuscript, following referees' reviews and comments. The experimental work in Alistair's laboratory is almost exclusively done on the computer using modeling programs, and thus the work moves along fairly quickly. The members of these writing teams, especially the post-doctoral fellows, are quite experienced in scientific research, and thus are able to compile and summarize their results quite effectively. The meetings of these writing teams were valuable in teaching students about using different styles of writing to target specific journals.

Writing Processes and Beliefs of Team Members

The writing team members' descriptions of the processes they used when co-authoring, as well as their stated beliefs about science, writing, enculturation and the co-authorship process, were stated in their questionnaire responses and also manifest in their actions during the co-authorship experiences. These data have been organized into three main activity-based categories: (1) planning to write, (2) writing, and (3) editing and revising draft manuscripts. The activities in these categories generally take place in stages 1 and 2 of the publication process (Figure 2).

Planning to Write

Cotton's Laboratory

Cotton acknowledged that, at times, the need to apply for grant monies influenced the purpose, topic, and content of his writing. Nonetheless, he maintained his belief that he had good, publishable results, that is, good science to report, usually influenced him to a much greater degree. With regard to his view of good science, Cotton described himself as being fairly rigid about the necessity of scientific rigour, for instance he described himself skeptical of huge conclusions drawn from small amounts of data. He also expressed openness and curiosity about new ideas and reluctance to remain anchored to old ideas. "I have gone into a situation really believing and thinking that something is a certain way and then having it completely turned around. And if you can do that, it means that you're not just selling your own personal agenda. You are trying to find out what is going on. Sometimes you have to be very confident to do that, because it overthrows a lot of your work." Rayne's estimation of whether she should begin writing her results depended heavily on Cotton's opinion: as her research supervisor, he helps her judge the rigor of her work, the worth of her findings and their readiness for publication, and the journal to which she should submit. Rayne expressed openness and curiosity similar to Cotton's, describing herself as agreeing most with an evaluativist view of the nature of science noting "…however, in my own work, I usually become intrigued by what goes AGAINST my hypothesis and seek to understand why a fact refuses to fit. I think I might be a combination of image A [absolutist] and B [evaluativist] in this regard."

Cotton and Rayne exhibited evaluative beliefs about the nature of scientific experimentation during their planning meetings. Between the first and second meetings Rayne gained an unequivocal identification of the major protein in the tsetse midgut. Cotton called it "a complete reversal", but he did not regard it with disappointment. Both writing team members were excited about Rayne's finding, and acknowledged that getting unexpected results was part of doing science. Indeed, Cotton was very proud of Rayne's initiative and critical thinking abilities. "At one point during the laboratory work Rayne invented an experiment where she measured whether or not the …bacterium can secrete this [protein] all by itself. …Logically it should, and it does -- here's the figure to show it." Rayne took a risk with her time and also her supervisor's time, and it paid off well.

Alistair's Laboratory

When asked how he decided what he would write about, Alistair said, "When I solve a problem, I write it up for submission to a journal. I only like to work on fundamental questions: I hate to just put a little twist on something that has been done." His students concurred. Karin pointed out "I write something down as soon as I have some model results which are new and could be interesting to other people." Daniel stated, "So far my supervisor has been the one with the ideas. I then carry out the research and once we think we have a story developed, I start writing, often re-doing the research as I write from a slightly different angle, so as to be consistent with the story, which hadn't been known before." Victor described his strategy: "Writing is the final part of what can be regarded as research, which normally consists of (1) idea, (2) literature review – what has been done so far, (3) research (running models, processing data), (4) writing the paper – I consider my results are publishable; this is not always the case." Alexander spoke to his decision. "After I get the impression I reached some robust conclusions, I start the writing process."

Alistair expressed an evaluativist view of the nature of science. "Science itself is about trying to understand how things work…science always opens more questions than it solves. It's about debate." Alexander also described himself as evaluativist, noting the postmodern viewpoint was "senseless" because it lacked the ability to apply objective measures to an analysis. Karin leaned more toward the absolutist viewpoint (80% absolutist and 20% evaluativist). "The simplest way to find plausible explanations of nature's laws is to deduce them from observations and measurements and as our methods of observation improve over time, Image B [evaluativist] describes pretty well the temporal evolution of sciences. Image A [absolutist] describes the best way I consider Sciences; it omits however the fact that some theories have been found to be pure theory and could be proved only later when the methods were good enough." Daniel chose an evaluativist image, noting, "I would add …that hypotheses are usually only developed in hindsight. All knowledge is subject to revision, but obviously some things are more sound than others." Victor did not agree with any of the images of science, stating, "I don't even agree that there may be a definite image of science." Ryo took an evaluativist stance because the word unchanging in Image A [absolutist] did not sound right and Image C [relativist] "doesn't make sense." Ryo said, "I like 'develop' and 'repeated evaluation' in B [evaluativist], but I don't agree 'most evidence the scientist would likely collect would support the existing hypothesis rather than refute the hypothesis.' Even if it is instructive, scientists don't get funding in [the case of] a negative result."

AT#2 (Daniel and Alistair) met twice to review figures (from his data analysis) and to decide what information to include in the paper, and to decide on a journal. In the first meeting, Alistair asked Daniel many questions about his findings and used a "think aloud" technique to logically piece the story together and to decide which figures to include. Daniel took notes during this process. In the second meeting, Alistair suggested to Daniel that he might consider writing the paper for a 600-word submission to Science, a journal with a broad science audience as well as some excellent media readership. This led to a discussion of Alistair's experience with learning how to write for a larger, more general audience. He noted that he worked with a journalist who helped him see that heavily technical writing just would not be picked up by the press. "[Being accepted for publication] depends on the reviewers and the they will not question the science. The science is good; the science is solid. The question with Science is does it have enough impact with a wide enough community?" Alistair suggested that Daniel focus on one key finding with two supporting figures for the short article, and also write a longer (1500-word) systematic, technical paper "wrapped around" his key result with supporting figures.

Alistair promised to work on the first draft of the Science paper, to "jazz it up a bit," and then meet with Daniel to discuss the suggestions.

AT#3 (Alistair and Victor) met to discuss the results of Victor's sea-ice modeling experiments. Victor brought with him a series of colour figures he had produced on the computer and a brief outline or sketch of the paper that suggested possible figures to include. He had shown Alistair the figures briefly beforehand, and Alistair had agreed he was ready to begin planning a publication. Victor's work was quite *avant-garde* in that he had considered the case of no winds over the oceans as one of his modeling assumptions. Alistair referred to this impossibility as a what-if hypothesis. "You often hear about the 'scientific process.' But then you ask well what would happen if I turned all the winds off over the world's oceans – it's ridiculous but it helps you understand the role of winds on sea ice." Victor explained the model he had used and reviewed his results and figures. Once again, Alistair began to think aloud, piecing the story together. He found one particular part of the experiment to be somewhat tangential to the story and advised Victor to remove it. Alistair also advised Victor to put together a self-explanatory title. The title they agreed upon was "Importance of Wind-Driven Sea Ice Motion for the Formation of Antarctic Intermediate Water in a Global Climate Model." They decided to submit the manuscript to was Geophysical Research Letters. They also discussed the length of the article, which was prescribed by the journal. Alistair believed that the paper would likely be done very quickly, as Victor "works fast!"

Writing

Cotton's Laboratory

Cotton and Rayne used nearly the same terminology to enumerate the constituents of a well-written scientific paper. They listed clarity, logic, appropriate introduction/stage setting, and good explanation and interpretation. Rayne concluded "In a nutshell, a well-written scientific article [features] thorough, well-thought-out research explained in an elegantly simple way or format." Both Cotton and Rayne said they judged science writing in the popular press differently than they did science writing in refereed journals. Cotton felt the popular press should relate more to peoples' lives and explain science in those terms. Rayne found the journalistic style of popular articles interesting to read, but she was usually skeptical of the science featured in the articles.

The writing team members considered the writing they did to be scientific – although Rayne did mention that her personal communication tended to feature scientific concepts expressed with non-scientific imagery and words. Cotton reported that he ensured accuracy and understanding in his science writing first by thinking about what he had written, and second by asking someone in his area of expertise to read the text and offer criticisms and suggestions. Rayne said "Can ideas ever be accurately or completely understood by those who do not create them?" Clearly, Rayne realized that constructing personal understanding accomplished one goal, while bridging the conceptual gap between author and reader is another equally important task to consider if a scientific claim is to be accepted by the academic community. She described editing and questioning her work, looking for multiple references to back up her statements and having Cotton or other graduate students read and critique her work. Both also recognized the influence of referees in their science careers. Cotton described dealing with referees suggestions. "How do I deal with referees comments – with great care because I want to be published! I treat each comment in its own way and sometimes I agree, sometimes not. I have strong views about the way science is presented. Clarity wins over almost every other aspect of my writing." When asked whether writing helped them understand their work, Cotton and Rayne spoke metaphorically of writing as 'helping to expose holes' in their data, thought processes, or methodologies. Rayne noted, "Writing usually helps me conceptualize what I am doing in terms of the big picture."

Cotton described the process or strategy he used when he wrote. "I almost always write the easy bits first – the methods, title page – then the results, the introduction, the discussion, and the references. I write the abstract last." Rayne described a similar process, noting psychological advantages of starting in the middle of the paper. "Cotton encourages us to start with materials and methods because it's our own stuff. When you get it down you get some momentum, and all of a sudden your paper has bulk. The end part is the hardest, but at least you've got something…you have a better understanding of what you have done and you can pick out what is pertinent." Rayne also expressed a feeling of frustration with writing poorly when she was working to deadlines. She noted a sense of accomplishment, though, when completing the project and seeing the results of long hours in the laboratory finally in print.

Cotton and Rayne depended heavily on outlines in their writing, and these outlines were revised to satisfy their ideas and their intended text. Cotton made four or five drafts of his outline, which included the points he wanted to make along with the figures and tables he intended to include. Rayne reported that she also made a preliminary list of questions to guide her methodology. She used the questions to make a flow chart that traced her laboratory work and gave her a structure for putting her paper together. Outlines provided by this writing team illustrated these processes. Rayne's outline included keywords, a sketch of the introduction, and a comprehensive explanation of the methodologies used. The summaries of results were based on the figures and tables she wanted to include, and they were very detailed. Cotton drafted an outline for the paper, also based on the figures derived from the experiments. His outline recorded the logic that he and Rayne had used to make decisions about the next steps in the experimental process. For instance, under a description of a 2-D gel, Cotton noted "Therefore points us to symbiont proteins as major…Because 3 symbionts of tsetse are known…Therefore grow Sodalis; run 1-D gel."

Both Cotton and Rayne reported doing literature searches on their topics before and during the composition of a paper. Rayne noted that she had to do library research throughout her writing because she had to know what was being published in her specialty to augment her claims and evidence, and to speculate what the competition was doing. If it looked like someone was working up to publishing findings similar to hers and might be ready to scoop her ideas, she might consider submitting a short research note rather than a full research paper, in the hope of getting her results into the literature faster. This competition did not extend to the work of her collaborators, however. Rayne showed a great deal of academic civility in considering a co-author "I really don't want to come out first with my…sequence …and subtract from the work that she has done. ...I don't want to step on her toes."

Cotton and Rayne maintained that their expected audience dictated the type of language they used. Cotton stated, "I tailor make my writing to reflect the expertise and interests of my audience." He maintained that analogies often helped him explain complex ideas. Cotton described using an analogy to illustrate the structure of a virus to a lay audience. "You put it in terms of what people have experienced…for instance, if you take a golf ball and shrink it down ten million times, that's what a virus might look like. Little dimples on the surface, hard shell on the outside – protein – protecting the gooey stuff in the middle – DNA and RNA."

During both meetings, Cotton and Rayne discussed the nature and size of the audience they were targeting. This led to a discussion about journal selection. Cotton stated, "Certain people studying sleeping sickness or vector disease transmission would be interested, but you wouldn't want to go strictly to a medical journal because they won't understand the paper." Rayne agreed. "You wouldn't want to go strictly to a bacterial journal because they wouldn't understand the implications of it."

In the second meeting, Cotton told Rayne it was time for her to begin writing the paper. Her reaction indicated to Cotton that she needed some guidance. He began to question her about what she would include.

Cotton: So what are you going to say with this paper?

Rayne: What am I going to say?

Cotton: Yeah, what's the idea?

Rayne: I've identified the major proteins in this. So what I have seen in the mid-gut is being that of a GroEL simply because of this.

Cotton: Period.

Rayne: Period.

Cotton: Ok now, if I was to be a devil's advocate, a referee, I would read this and say well there is your 2-D gel spot, all you did was you took that major spot and gave it to the mass spectrometry analyst and bang it is identified a Wigglesworthia GroEL, period.

Rayne: No, because all of the rest of the information actually said Sodalis. But had the story been changed it would have been the other way around.

Cotton: So isn't it just worthwhile publishing the one result, just a short note, to the research community? The major protein is Wigglesworthia GroEL period. That is what the information is.

Rayne: You probably could do that and then publish a bacteriology paper on Sodalis.

Cotton: But you think that by telling the story that shows the methodology used and the logical reasoning that led you down this path, that that's important in itself?

Rayne: Absolutely. And I think it shows how mass spectrometry can be used to distinguish between different species in a protein mixture.

Cotton: Yeah, and that things are highly related to each other.

This discussion helped Rayne decide to write a full-length paper that focused not only on her findings, but also on the methodology she had used.

Alistair's Laboratory

The Atmospheric Writing Teams identified clarity, accuracy, completeness, and logic as the main characteristics of a well-written scientific paper. Karin mentioned this kind of paper would contain new ideas. Daniel noted that the writing would be dynamic, that is, written in active rather than passive voice, and that the paper would be built around one or two central themes. Victor stated that a well-written scientific article would "very clearly explain the basic idea, even if it did not fit a 'common' point of view." Alistair contended that the audience to which an article was being written influenced his definition of well written: An article written for a scientific audience could reasonably contain a great deal of jargon and discipline-specific language, whereas an article written for public consumption would have to be written more simply in terms the audience could relate to. Much like Cotton, Alistair regularly uses analogies and metaphors to explain very complex topics to non-expert audiences.

Alistair, Alexander, Karin, Victor, and Daniel were somewhat suspect of the science reported in the popular press, unless they were familiar with the writer and trusted his or her willingness to check facts and seek clarification. Ryo had a different opinion "I do not make a difference when reading a paper form either a peer-reviewed journal or from a popular one. If the paper seems interesting to me, I am able to judge the written material on my own. I do not think that all papers in peer-reviewed journals contain better science than those in the popular press."

Alistair and Daniel noted that they routinely wrote for non-science audiences: Alistair had written op-ed pieces, policy papers, papers for refereed educational journals, and letters to the editor on educational reform issues. Daniel had written grant proposals and progress reports to granting agencies. He believed that less formal writing, for example, e-mail correspondence about experiments and popular science writing "could be considered scientific since it discusses scientific investigations and has at least some sort of peer review, which I feel is a crucial requirement of scientific writing." Alistair reported that he ensured accuracy and clarity of his ideas in his scientific writing by checking them against original sources and by having staff members read the papers for clarity. Daniel, Alexander, and Karin noted that they had co-authors and others read their work and offer suggestions for discussion. Victor and Ryo noted that they talked to colleagues about their papers, to see if these individuals understood the topics and were interested in them. Ryo also mentioned the value of presenting his results at conferences and receiving feedback.

Alistair reported that he found writing helped him improve his understanding of his work. "There is nothing better than having to write a review article if one wants to spin off into a new area. Having to communicate a different scientific concept to the public means you have to really understand the issue." Karin noted that reviewers' comments sometimes helped her better understand her research or prompted her to consider alternatives. Alexander found the writing process helped him focus on the essentials. "It forces you to look at your work from a more distant point of view. This almost always leads to a better understanding of research by putting it in a better context." Ryo noted that he tried to critical when he read his work and that improved his understanding. Victor maintained that writing is always part of research: in this instance, it spurred him to read new literature, contact new people, discuss his results, and summarize his new knowledge. Daniel was definite about the role writing played in helping him understand his research. "It is very easy to get rather focused on narrow issues, and in the end you have solid results on branches of what you were originally planning. Writing the paper forces you to reconsider where all this fits in to the general field."

Alistair described the process he used when he wrote. "I start by figuring out who my audience is; brainstorm bullets that represent sections or paragraphs I want to include; order bullets so the piece follows a theme; and start writing. This is pretty consistent for everything I write." Each student appeared to have a somewhat different approach to writing. Daniel stated he didn't use a formal outline; he termed his writing process as a "core dump method…I simply sit down, write more or less straight in one go, and then do extensive editing, pasting, cutting, switching, adding, et cetera. The idea is to get a frame to build around. The process differs only really for longer things, such as journal articles: in that case I tend to segment the process into the various sections (for example, introduction, data, and method, results, discussion, and then try to synthesize them." Victor used a one or two page outline. He stated, "I normally start with results. This is the most important and most difficult part, I think. Then comes the introduction, some other important details (like the model I used)…then I re-read the whole thing, correct, re-read again and try to write the conclusions." Alexander did not report using an outline nor having a general pre-writing strategy. "For short papers, I usually start with the figures. I select figures I want to show and think about the order in which to put them following a 'story'…If I have developed the 'story' it is quite straight forward to work it out in detail in the main text." Karin described writing down important ideas then rearranging them in logical order, thus her outline appeared as she wrote. Ryo stated his outline was "only in my brain. Since I am doing modeling, I imagine the experimental design, the results I have, and a few conclusions." Alistair and his students reported doing library research on the topic before and during their writing. Alistair stated, "I am aware of the literature when I start but only write this bit at the end. As you write, you always find issues that need to be further explained."

Alistair referred to audience awareness the "key to successful writing", and all of his students cited recognition of the audience's knowledge as an important consideration their writing. Victor mentioned that both the language he chose to use and the length of the paper depended on the audience. Daniel also spoke about manuscript length "Usually I find that in many ways there is a certain length limit, and that often ends up forcing a limit on how technical it can be…[length limit] usually varies with audience and is usually imposed by them: laymen want summaries, experts want details."

Editing and Revising Draft Manuscripts

Cotton's Laboratory

Cotton revised each paper four or five times, especially those that were multi-authored. He asked other authors to edit his work and make suggestions, but mainly relied on himself for grammar and spell checks. Rayne also checked most of the grammar and spelling herself. Cotton described himself as open to direction and suggestion from co-authors in the planning of experiments, the interpretation of results, and the expression of findings. He also described having an appreciation for referees' comments, because they sometimes made him see that he had neglected to include pertinent details. Rayne described numerous rounds of review and revision, first with Cotton who edited for ideas and concepts. He sometimes "slaughtered" her first draft, and sent the subsequent four drafts back for more work. After about the fifth draft, the manuscript was ready for other eyes, usually those of her laboratory colleagues. At the point where the manuscript is nearly ready to submit, Rayne sends it to off-site co-authors for their information and feedback. This final edit ensures that the collaborators are aware of and approve of the contents of the article; it also may provide more information about what is being done in the field, or perhaps alert her to suitable journals to submit to rather than the one she and Cotton have chosen. Rayne likened the internal process of editing to peer review.

The following two versions of Rayne's paper (6^{th} edit) were taken from the last paragraph of the introduction:

Rayne's version: Identification of influential midgut proteins using standard protein chemistry is impossible when analyzing a complex mixture of molecules, in this case both insect and microbial in origin. Matrix-assisted laser desorption time-of-flight…are the methods of choice for protein identification. Peptide-mass fingerprints (PMF) from trypsin-digested target proteins are used to interrogate protein databases with either mass or sequence information. Using this proteomic approach, we unexpectedly identified the predominant tsetse midgut protein as being a microbial chaperonin.

Cotton's version: Identification and characterization of proteins present in only small amounts of materials, such as tsetse midgut is not easily performed by standard protein chemical techniques. Although molecular biology techniques can be powerful tools for gene discovery, the linkage

> disequilibrium often encountered between …can lead to false assumptions about expressed proteins. For this reason, we have used protein microchemical techniques and mass spectrometry to identify major proteins in midguts of teneral *Glossina morsitans morsitans.* Using this proteomics approach, we unexpectedly identified the predominant tsetse midgut protein as a microbial chaperonin.

In Cotton's edit, Cotton and Rayne seem closer to the science: they identified the protein as a microbial chaperonin. Cotton also has helped Rayne better develop a line of reasoning that sets the stage for the final sentence, which is the key finding of the paper.

Rayne and Cotton were very close to submitting their paper at last contact. Both acknowledged that the process was lengthy and arduous; they also agreed that the end result was worth the effort. Cotton stated, "[To substantiate our conclusions] we have to prove that the protein is from a microbe and not the tsetse fly. And that's what takes a lot of time. I'm confident that this is a microbial protein. …We could have written the paper up three months ago and sent it in, but to prove it [takes time]…a sharp referee will just say, yeah, it is not good enough evidence so go back to the drawing board."

Alistair's Laboratory

Alistair described revising continuously, every page or so. His students also revised many times; one used the term "constantly re-reading and revising." Daniel stated, "Most of the writing process is revision for me. Typically, I go through the equivalent of about half a dozen drafts before finally sending it off to the audience or other authors." Victor described his process. "I switch to something else for a week, then re-read the paper with a 'fresh eye,' correct it and so on. Finally, when I feel it can be considered as a preliminary draft, I give it to my co-author(s)." All of the members of Alistair's team had other members, co-authors, and scientists edit their work and suggest changes, though none had used the services of a professional technical editor. The students who considered English a second language often asked native English speaking friends or fellow students to proof read their work and check their grammar. Most used computer programs to proof their spelling.

AT#1 (Alistair, Karin, and Alexander) were quite well advanced in drafting their paper "Forcing of the Deep Ocean Circulation in simulations of the Last Glacial Maximum" when this study began. Alistair had edited two full drafts and both students had edited at least three. Alistair's first edit centered on the science in the paper: his questions often began with "Why…" and his comments mostly began with "Explain," "Discuss," and "Add reference." His second edit still focused on the science; however, he made a number of suggestions about syntax, grammar, and sentence structure. Both affirmative remarks such as "Nice!" and critical remarks such as "No, I don't see this" were evident in Alistair's edits.

During the meeting, the triad talked at great length about the journal to which they would submit the manuscript. This brought up a discussion of audience, which soon turned into a discussion of who read the journal they had chosen, Paleoceanography. Karin understood that geochemists – the primary readers of this journal – did not like modeling papers. Alistair agreed that might be true, and, in any case, they would likely read the abstract, the last paragraph of the introduction, and the final two paragraphs of the paper, so that is where they had to put their main message. He admitted that, because he had so much to read, he sometimes used this method of screening papers. Alexander pointed out that scientists other than geochemists read this journal. The group chose to stay with their initial decision.

Alistair reviewed his comments with Karin and Alexander, noting that they needed a strong conclusion and that they must indicate that the model they put forward was a substantial improvement over older models. He also advised them to explain their decisions. Alistair put himself in the place of a reviewer. "I would ask if you have this moisture at wind stress feedback, why aren't you using it? … You caveat [the results] beautifully at the end [but] this is in the wrong place. Be specific about why you did what you did." Alistair suggested omitting two entire lengthy paragraphs near the end of the paper, but Alexander opposed this decision. Alistair relented, with the understanding that Alexander would include a "motivating" introductory sentence and use an illustrative example.

The manuscript was submitted and the writing team subsequently received comments from three referees. It is noteworthy that Paleoceanography and many other similar journals sometimes use a double-blind system for reviewing papers; however, in all cases the reviewers know the author's identity. AT#1's case is unusual in that both the reviewers and the writers knew each other's identities. These reviewers may have chosen to sign their reviews because, overall, the comments they offered were very positive. Karin noted, "This is the first time this has happened to me!" The paper was recommended for publication after a few revisions (one reviewer prefaced two of his suggested changes with "If the authors agree…"). The referees asked for further explanation in some areas (to better explain the science and justify the conclusions), and clarification of a few terms. They included a few comments about the proper use of language (jargon) such as "kyr BP" rather than KBP. Two reviewers suggested additional salient references be added.

AT#3 (Alistair and Victor) completed their paper "Importance of Wind-Driven Sea Ice Motion for the Formation of Antarctic Intermediate Water in a Global Climate Model" during the course of the study. Victor's written English is good; however, he does require editorial assistance. Alistair did a substantial edit in which he corrected Victor's grammar and word usage, as well as suggesting changes to make the introductory and concluding sentences declarative and thus more emphatic. For instance:

> *Original version*: When neglecting a direct momentum transfer from wind to ocean the model is still able to simulate reasonably well a tongue of relative low salinity, provided that the wind stress is applied to drive sea ice.
>
> *Alistair's version*: The model is still able to reasonably simulate a tongue of relatively low salinity AAIW even when the direct momentum transfer from wind to the ocean is neglected, provided that the wind stress is applied to sea ice.

In the final section of the manuscript, Alistair replaced "it remains uncertain" with "one cannot exclude…" He also shortened the concluding paragraph to one emphatic sentence: "In conclusion, we suggest that sea ice dynamics should not be ignored in coupled models where a reasonable representation of southern hemisphere deep ocean ventilation is desired."

The manuscript was submitted to Geophysical Research Letters and was recommended for publication after revisions by two referees. Both referees were complementary of the science in the paper. Their comments with respect to revision centered on questions about some of the findings (i.e. request for further elaboration or more evidence), adding a further citation, clarification of terms and greater specificity, and omissions of words and typing errors. Alistair and Victor responded to the comments, focusing on three major changes to the manuscript: (1) the inclusion of a new modeling experiment; (2) justification of their use of certain model-simulated information; and (3) the inclusion and discussion of a suggested reference.

AT#4 (Alistair, Alexander, and Ryo) were nearing the end of their drafting process on the paper "Instability of Glacial Climate in an Earth System Climate Model" well before the beginning of this study. They each had reviewed and reworked at least two drafts and were confident in their scientific claims. Their meeting focused on the submission of the paper to Nature, a very prestigious science journal. Alistair had edited the manuscript, changing the style of the writing, but not the science, so it would be more acceptable to the journal. Examples of the editing follow:

> *Original abstract*: Since the analysis of the first deep cores from the Greenland ice sheet in the nineteen eighties (references listed APA) it is known that the climate around the North Atlantic has been much more variable during the last glacial period than during our present interglacial, the Holocene. Rapid, high amplitude transitions between cold and warm states occurred repeatedly on millennial timescales.

> *Alistair's edited abstract*: Analysis of the first deep cores from the Greenland ice sheet (superscript reference numbers) revealed that the North Atlantic climate was much more variable during the last glacial period than during the present interglacial. Rapid, large-amplitude transitions between cold (stadial) and warm (interstadial) states occurred repeatedly on millennial timescales.

> *Original text:* The inclusion of an interactively coupled dynamical land ice model component enables us to investigate possible forcing mechanisms for the transitions. We demonstrate that a reduced calving of ice bergs into the

North Atlantic, which might have happened after a massive surge in northern hemisphere ice sheets, is a possible trigger for an abrupt switch to a warmer climate state.

Alistair's text: The inclusion of an interactively coupled dynamical land ice model enables us to demonstrate that reduced calving of ice bergs into the North Atlantic, following a massive surge of northern hemisphere ice sheets, constitutes a trigger for an abrupt switch to a warmer climate state.

Original Conclusion: We suggest that active ice sheet model components are included in simulations of past and future climate change, particularly if changes of the Atlantic overturning are considered.

Alistair's conclusion: We suggest that possible answers to these questions will only be obtained from simulations using coupled atmosphere-ocean general circulation models that must incorporate comprehensive continental ice sheet models, particularly if changes of the Atlantic overturning are to be considered.

The meeting discussions centered on styles of writing and the issue of editing and ownership. Ryo attended the meeting, but his main contribution to the paper had consisted of doing the modeling, and thus he did not enter into the discussions about the writing. Alexander, first author of the paper, was very concerned about ownership. "I think generally it improves the writing style but I have to say, I really don't want someone who reads the paper, to say, oh that's Alistair's style. …I mean [if it is published it would be] because one famous guy is on the paper. Even if he is not the first author, everybody thinks it is his paper and the other guy maybe did the work, but Alistair is the one who really did this paper, or had the idea. So I'm going to take all your suggestions and I'll see what a difference they make, but I'm going to rewrite it, in my own style."

Alistair was very blunt in his reply to Alexander. "OK, I'll tell you that this paper, as you wrote it, will not be accepted. It would be rejected because of the way it was written." He went on to praise the science and try to explain why the style would not be acceptable to Nature. He described re-writing the abstract, parts of the introduction and the concluding sentences. "This is what the Nature editors are going to read. …They are going to scan through this, but the reviewers are going to read this, that's what gets it into Nature. And then they come back and they read the conclusion." Alistair had edited the abstract, making sure the main topic was clearly outlined and that phrases such as "no study to date" were included where applicable. Alistair also cautioned Alexander that, to make it acceptable to Nature, he would have to stay with one story throughout the manuscript and be very careful to not include extraneous information.

Both Alistair and Alexander demonstrated academic civility and were very respectful of one another during the tension of the debate. Alistair noted that the word 'enigmatic' was Alexander's and that he had had to look it up to get its meaning! He agreed that it was the perfect word for the context. Alistair also praised Alexander's initiation of the acronym 'AMOE' to replace 'THC,' noting the latter had other connotations. Alexander maintained that working with Alistair was of great advantage to him and that he appreciated the opportunity.

Alistair clearly had Alexander's best interests at heart when he edited the manuscript, and he tried very hard to convey his reasons for making the changes: "You are trying to get a reputation. This is how you do it. This is the way it is done. …Your work is good, the next place you go, I mean, you build a reputation by doing the same quality stuff for each institution, and they know it is yours. This is not my style, this is Nature's style." Alexander was not unappreciative, and he acknowledged "Of course, that's the big advantage you know…that we are together." Alexander agreed that perhaps Alistair was right about the writing style being important, but he could not put the writing before the science. "It's the science. If it's really something very important, it should be published in Nature even if it's written by someone who barely speaks English."

The meeting diverged from the discussion of the writing style and Alexander asked Alistair questions about the science. Alistair suggested a further citation in one instance and assured him the science was excellent. He then brought Alexander back to the issue of style and publishing. He assured him that because he was first author, he had final say in the manuscript. Alexander accepted this saying that while he saw that Alistair's editing had added polish to the paper "I mean, you have to start somewhere …but I have the feeling I have to do it my own. I have to, you know, I have to learn for myself right now." Alistair accepted this with a great deal of equanimity, although he did try once again to explain that the work was still Alexander's and that by accepting his editing suggestions, Alexander was by no means diminishing his role in the co-authorship. "You can learn through the school of hard knocks, which is the way you are suggesting which is having a paper rejected or you can learn … from [the collaboration]. If you are going to change it, I would not go back and change the [original draft], but change this [edited version]. And that's perfectly fine, I mean, that's my job…and it will be your job when you get your faculty position. …My job has a teaching role as well."

Team Members Beliefs about the Effects of Co-authoring

The writing team members were asked a series of questions about their co-authoring experiences including the nature of the experience, the most valuable aspect of the experience for each of them, and insights they made during the co-authoring. Their answers are summarized in this portion of the chapter.

Cotton's Laboratory

Cotton reported that the co-authorship experience with Rayne was similar to ones he has had with other students. He noted that Rayne was an excellent proof-reader and thus the first drafts she submitted were good. However, careful proofreading caused her to be a bit slow in submitting her writing. Cotton believed that Rayne had shown improvement in her writing during this experience. "She has always expressed herself well but would sometimes add superfluous material, just because she wanted to add everything. This tightened up as we went. Her critical thinking has always been there; she's one of the best graduate students I have had with respect to knowing what is required and expressing herself. These skills have been sharpened. Speed will come once she learns how to get over the fear of handing in something that isn't complete."

Neither Cotton nor Rayne believed that being observed during this study affected their interactions. It is noteworthy that about half of the meeting time consisted of a discussion of the work Cotton and Rayne were doing, including a description of the anatomy of the tsetse fly, a discussion of the trypanosomes inhabiting portions of the anatomy, and an explanation of the method of separating and identifying proteins in the midgut of the fly. Cotton and Rayne became enthusiastic teachers, often completing one another's sentences. These explanations at first appeared to be purely for the benefit of the observer; however, they brought to light some unresolved disagreements or questions about methodology or findings. They also gave Rayne an opportunity to think aloud about her work. Cotton often prompted Rayne with questions, thus scaffolding her self-confidence as a scientist and giving her an opportunity to show the scientific expertise she had gained. He maintained that indeed he was not the expert during the entire process. "Rayne was up on the details of the experiments and had thought about their meaning. I contributed on the organizational aspects, ways to present the materials." Cotton believed the most valuable part of the co-authoring process to Rayne was the amount of talking they did about the experiments. "It's a way of formalizing the experiments; the holes are always evident when you try to present a story with figures and tables, et cetera. The process is always valuable to me since it brings me closer to the details of the work, as I am not always on top of the day-to-day details." Cotton further maintained that by asking questions about the data during the process, they were led to do more experiments on ideas they had not previously considered.

Rayne's response to being asked whether the co-authorship process affected her writing was both amusing and eloquent. "Did the co-authorship affect my writing? Is a sea urchin covered in spines? My writing is now smoother and more precise. …My mind has been forced to critically think about the research from the bias of either an external examiner or the general readership instead of only a primary researcher. Thinking this way has given me more insight into how to present the writing and what to include in the writing with regard to content." Rayne reported that this was the first paper she had written targeting a major scientific journal, so she had no expectations going into the process. She noted that she learned a lot about the readership and the journal, and that the selected journal was "a marriage of entomology, biochemistry and molecular biology so the audience is of a medium size." Rayne reported that, during the co-authorship process, she had learned to abandon her teaching voice and focus on the presentation of scientific findings. Rayne said she had made new insights into her target science area. "How many times was a tentative outline for a paper written, only to be changed by either new scientific data, input from a collaborator, or brainstorming and revising of previously hatched ideas! Cotton challenged my ideas, acting like a review committee, so that I was more aware of what was required with regards to the clarity and comprehensiveness of my work." Rayne referred to herself as a "giant sponge", maintaining that the supportive laboratory environment empowered her to first think and then correct her wayward thoughts, without "debilitating criticism". She greatly valued her relationship with Cotton. "He was my partner and mentor simultaneously. What he did not understand, I tried to teach; what I could not do, he showed me how to do by example. I know this is unusual in the realm of graduate student experiences and feel very fortunate to be in this situation."

Rayne maintained that a formal course in scientific writing would benefit both the advisor and the graduate student. She believed it would expose novice writers to what is involved in making a paper worthy of publication. Rayne also believed it would hold the advisors more accountable. "It is common to hear of students' woes in writing when there is little feedback from the professor. The student can often submit unpolished work for publication, only to be rejected by a journal review committee. Had the advisor been aware of what was submitted and/or the student aware of what they can ask from the advisor, the article undoubtedly would be written to a higher standard." Rayne also noted the value of a formal course could help students understand the components of "publication worthy" experiments; for instance, the importance of running controls. Incorporation of information about data manipulation and making figures would also be useful. "I cannot tell you how many hours were wasted in just the learning how to use EndNote for bibliographical databasing, how to decrease the size of a figure without altering the pixelation, how to use the various file storage options." However, Rayne noted, scientific writing is more than just mastering the tools of word processing and data; instruction on these peripherals would be necessary but not sufficient in a scientific writing course.

Rayne believed that by working with someone with so much experience, she was able to see weaknesses in her own writing. She described enjoying the creative process. "Ideas would gallop around like wild horses. Taming of those ideas and working them into a professional format alongside a trainer and friend showed me that the process can be somewhat enjoyable and very rewarding as in the end, you are left with a fantastic template from which to mould subsequent papers." She believed Cotton benefited from being able to see what was happening in the laboratory, and also by learning more about the subject and being able to add the "new endosymbiont angle to his overall plan of attack on the tsetse problem."

Alistair's Laboratory

Alistair maintained that his experiences with AT #1 and AT#2 were similar to those he had before with similar types of students. His experiences with AT#3 and AT#4 were atypical. Victor in AT#3 needed help with his written English. AT#4 was composed of a post-doctoral fellow and a graduate student.

Alexander took the lead in writing the paper for AT#1, with Karin providing the modeling expertise. Alistair stated that in AT#1: "Alexander did tighten the story after my input and cleaned up some loose ends. I think our discussions assisted in this process although he definitely knows how to write well." Alistair noted that in Daniel's (AT#2) writing had improved, and that Victor (AT#3) was becoming more and more thorough and clear in his writing. Alistair noted "Victor is also seeing how to expand a story to make sure there are no extraneous details and all loose ends are tied up." Alexander's role in AT#4 provided him with an opportunity to learn a different style of writing (Nature rather than the traditional scientific research journal). Alistair stated: "Alexander began to see how one needs to write these pieces for the wide audience."

Alistair considered all the team members to be on equal footing as collaborators, noting in each instance "We were all experts in this [context] and [we] worked as a team." He mentioned, however, that his work with AT#3 (Victor) included re-writing to make the English more clear, and in AT#4 (Alexander and Ryo) modification of the manuscript to convey the findings to the larger audience of Nature. Alistair believed the students benefited from the co-authorship experience by "learning how to succinctly convey the results of many experiments and much data in a fashion that is; 1) easily understood; 2) interesting to the reader; 3) [relevant] to the field (for instance, setting it in the larger context); [and] 4) seeing a project through from completion to end." He believed that he benefited most by seeing the excitement in the students as they took a scientific problem from initial concept through to publication. "In addition, I love to learn new things about the science of climate."

Alistair noted that with respect to making new insights into the target science concepts, all of the teams had similar experiences. "The student wrote a first draft and presented the manuscript to me. I then responded either by recommending more work, rewriting bits, or providing suggestions. In all cases, when one starts to write one realises that questions arise. In some cases the student found the questions and did more work to answer them. In some cases, after reading the piece, I had remaining questions that required more work, figures, or experiments. These new figures and experiments always lead to a more complete understanding of the problem. The central storyline did not change in the writing but 'what about this' type questions would be addressed."

The graduate and post-graduate students were asked if they believed co-authorship had improved their writing. Alexander believed that the co-authorship experience improved his writing. Karin, who had provided the modeling expertise for this paper, did not believe it affected her writing, but she noted that co-authorship definitely reinforced her critical thinking. Daniel believed the experience helped him see weaknesses in his arguments. He stated his control and ownership of his writing was not affected: "In all cases and in the past, they have been my papers. The co-authors have always been suggestive rather than authoritative in comments, and some I have not implemented, although I have always explained my rationale to them, of course." Victor maintained that the co-authorship affected his knowledge, thinking, and writing. "In fact, I think that a paper which has more than just one author is always better, just because more people put their thoughts in it." Ryo saw co-authoring as a very beneficial exercise, because he learned about making the story clear and the conclusions definite.

Generally, the co-authoring experiences improved the students' understanding about the expectations of the target journal, audience, and science ideas. Alexander reported that he did not learn a great deal more than he already knew about the expectation in his experiences in AT#1, but his experiences in AT#4 increasing his understanding of a widely-read science journal. Daniel noted he would have to keep the technical level down for his target journal without "washing out the science." Victor believed he had a good paper and had hit the mark for his audience, but he awaited the referees' comments to see if he had. Alexander did not think that he had made new insights into the science ideas as a result of trying to express himself in writing, while Daniel thought he definitely had. Daniel stated, "When you come with an idea for research it tends to be: 'no one has done this before, and any results will be useful.' Once you get the results, it tends to be 'okay, so which of these results here are more important, surprising, and/or coherent for a story.' Writing forces me to focus." Victor maintained that the usefulness of the co-authorship could be seen in the way co-authors could direct or re-direct his thoughts, so that a seemingly complex physical process could become more understandable. Ryo said, "[I gained new insight] during the research but not from writing. It happened not because I am a co-author, but I am a co-author because it happened."

The co-authoring events were positively viewed when compared to previous events. Alexander saw himself as much more experienced in this co-authorship episode, and thus he had to make fewer revisions and the paper was completed more quickly. Karin enjoyed this co-authorship experience because she was working with someone in her office, and she would exchange ideas directly with him. Daniel noted that during previous co-authorship experiences, he never had been monitored very closely by his co-authors; "However, this time I was definitely given more free rein." Victor remarked that he had a lot of different experiences, but this was one of the best because he had an opportunity to learn. Ryo responded that he had the opportunity this time to focus on the main part of the story as well as the technical part (modeling).

Graduate and post-graduate students expressed mixed opinions about the value of a course in technical writing. Alexander believed that such a course might help students who had not written technical papers; however, he believed that reading a number of other papers might also be very helpful. Karin believed that authentic experience was the best way to learn. Daniel stated, "I do not think it would have helped me here. It could perhaps be useful for other students, but I think generally this is covered in other courses through term projects, for example. I think that this kind of writing is good training. …I think the biggest problem is a matter of people not putting the effort into polishing a paper, not thinking that this is as important as the results." Victor and Ryo, two students for whom English was a second language, expressed interest in a technical writing course.

None of the members of the atmospheric physics writing teams believed that being observed affected their interactions. Daniel noted,"Meetings tended to be more formal only in the sense that they were actually called 'meetings.' Otherwise we would have tended to break it into more frequent chats of a few minutes duration."

These students believed the greatest benefits derived from being involved in the co-authoring experience were journal awareness, collaboration, and scientific insights. Alexander noted that he gained most from the writing experience of his supervisor and from the opportunity to evaluate the science in his papers during the drafting process. Karin appreciated the proximity of her co-authors and their willingness to discuss the paper. Daniel learned how to write for a more general journal. He also hopes to gain scientific currency in the form of a published paper. Daniel believed Alistair also benefited by gaining this currency. Victor believed the new knowledge was the most valuable to him, and likely to Alistair as well. Ryo stated he learned a lot about writing for a different type of journal that he considered "politically influential".

Assertions

The following three assertions are based on the evidence presented in the preceding sections of this chapter. They address the three research questions:

1. What are the activities and processes inherent in the co-authorship of research documents? (Assertion #1)

2. How do the graduate student's or post-graduate student's and the research supervisor's beliefs about writing agree or disagree? (Assertion #2)
3. Does co-authorship help the student become an expert science writer? (Assertion #3)

Assertions appear in bold face and researcher's elaborations in normal type.

Assertion #1: Several activities and processes are common across all co-authorship teams. Aspects of scientific literacy are inherent and evident in these processes, as are elements of scientific and writing expertise, facets of enculturation into scientific research and discourse communities, and the dynamics of collaborative groups.

All members of the writing teams decided when to write and what to write based on their confidence that their science was solid and worthy of publishing. Students relied on the opinions of their supervisors. All but one of the co-authors used either a mental or a written outline to organize their results before writing. Both research supervisors used a think aloud protocol or an embellished written outline of the research results to develop the storyline for the paper, and to model the metacognitive awareness and executive control required by science writers. They used research figures and tables as a basis for these activities, and to illustrate that the practical development of a research paper may not follow the traditional steps in a scientific inquiry. The research supervisors used these techniques not only to organize their own thoughts, but also to teach the students how to construct papers around a central theme represented in figurative results. All co-authors reported doing literature searches both before and during their writing.

All co-authors reviewed and revised their work. Not only did self and peer review help them ensure their science ideas were clear, it also helped them better understand their science. Thus review and revision were considered a critical part of writing, and, as a result, substantial time was allotted to these activities. Indeed, the writing processes described by the co-authors were neither strictly sequential nor discrete: all of the processes were iterative and overlapped. Editing often stimulated the co-author to return to the planning stage, and, in some cases, to the laboratory or the computer. In one instance, a second look at the findings convinced a writing team to undertake further experiments. Co-authoring could be considered co-constructing of science with the team members.

During discussions of revisions to text, co-authors frequently changed roles, with the student becoming the expert. Research supervisors used the authentic co-authoring processes and activities to teach the students about disciplinary culture, audience, language use, and style within discourse communities, and to model academic civility. Revision processes also allowed co-authors to express intrinsic principles such as loyalty, respect, and trust. Power and academic status were apparent in the processes, but they were never wielded with a great deal of force or in a negative fashion. The research supervisors might be considered benevolent interlocutors rather than didactic dictators.

Assertion #2: Graduate and post-graduate students' beliefs about science and the role of science writing appear to agree with those of their graduate supervisors in terms of the nature of science and the role of writing in science.

Co-authors exhibited the habits of mind such as scepticism, openness, and risk taking associated with an evaluativist view of the nature of science. Most reported Image B – Evaluativist best described their beliefs about the nature of science. They were naïve realists, believing in the sanctity of scientific fact while at the same time acknowledging the limitations of science and scientists, and accepting what Karin referred to as the "temporal evolution of sciences". In light of this conflicted approach to the nature of science (believing in reality, but being unsure about ever achieving an accurate image of this reality), it is not surprising that these modern scientists had difficulty abandoning the language of the absolutist view and that they commonly used words such as 'prove' and 'solve.' However, they also used hedges, indicating that they were not prepared in all cases to offer unequivocal conclusions, or declarations of absolute truths, and further evidencing of their evaluativist leanings.

Beliefs about disciplinary language and intertextuality likely could be subsumed into the co-authors beliefs about the constituents of a well-written scientific paper -- good science followed by good science writing. Clarity, logic, appropriate introduction and stage setting, good explanation and interpretation, and accuracy were mentioned, indicating an understanding of good writing in general and good writing within their respective disciplines. Audience also influenced these beliefs. Undeniably, considerations of audience and journal selection dominated the discussions of the style of writing and the length of articles. These topics did not supplant science as the co-authors primary concern, but they were a close second. Knowledge of the discourse communities and specific audiences helped the co-authors deal with the gatekeepers of the academy, that is, the referees and editors who could reject their science based on the inappropriateness of the style of writing they had chosen. Co-authors found that writing deepened their understanding of their science by helping them (1) identify inconsistencies or inadequacies in their data, their logic, or their methodologies, (2) focus on essential information, and (3) consider new ideas and alternatives. Writing in these co-authoring experiences fulfilled a constitutive role, as well as a communicative role.

Assertion #3: Co-authoring is an authentic and meaningful experience in learning how to write like a scientist.

Graduate students, post-graduate students, and research supervisors reported that these co-authoring activities promoted their critical thinking, increased their science understanding, and enhanced their writing effectiveness. Each writing team identified voids in their data, and weak links among claims, evidence, and warrants. The co-authoring experiences helped them construct more compelling arguments about the science. The students also believed the experience, including the tensions, helped them grow as scientists and become more persuasive, thoughtful writers. They learned that experimental inquiry in science, though necessary, was not sufficient – writing was not just the carrier; it was part of doing science. They learned about targeting their writing to a specific audience; specifically, they learned that journal selection affected their rhetorical goals and selection of language.

CHAPTER 5

DISCUSSIONS AND IMPLICATIONS FOR FUTURE RESEARCH

Introduction

This case study was designed to examine the co-authorship process in two research laboratories of different university science departments. The study, which focused on five writing teams, observed the role of the research supervisor, the role of the student (graduate and post-graduate), the interaction of the supervisor and the student, the activities and processes inherent in the co-authorship process, and the outcomes for the student with respect to his or her expertise, scientific writing, and entry into an academic discourse community. Multiple sources of data and methods were used to determine the activities and processes in co-authoring research documents, the alignment between the graduate student's or post-graduate student's and their research supervisor's beliefs about writing, and whether co-authorship helps the student become an expert science writer.

A purposeful sample of five writing teams, each comprising a research supervisor and one or more graduate or post-graduate student(s), was selected for this multiple case study. One team was selected from Biochemistry and Microbiology, so that results could be compared with a previous study (Chaopricha 1997), and four were selected from Earth and Ocean Sciences to expand the exploration of academic writing into a new discipline. The documented characteristics of the research supervisor participants were considered in selecting the cases. The two research supervisors who were chosen for the study wrote well, were well published, and were recognized as experts in their specific scientific fields (Yore, Hand & Florence, 2001). The research supervisors and their students were not necessarily representative of the greater population in science, in the specific disciplines, or in the host departments, but they offered potential opportunities to observe an exemplary, constructive co-authorship process. The results of this case study are not generalized; however, this thesis was developed to be generalizable by the reader. The reader must use his or her knowledge of similar settings and experiences to help understand the findings, and perhaps to identify experiences and activities in the study that could be investigated further or applied in his or her own context.

The graduate and post-graduate students were given a questionnaire to ascertain their respective background experience in science and their beliefs about science writing (Appendices B & C). The research supervisors had answered these questions in an earlier study (Yore, Hand, & Florence, 2001). Participants were then followed through the five-month drafting process of a research report manuscript. Research supervisors and their students were observed and audio-taped with their permission each time they met. Field notes and reflective notes were taken at each meeting. Edited drafts, including research supervisors' suggestions and students' responses, were collected. During their writing or soon thereafter, students were given part two of the questionnaire (Appendix F) to establish the methods they used when they wrote, for example, did they use outlines, did they edit and revise, and so on. The research supervisors had answered these questions in the earlier study (Yore, Hand, & Florence, 2001). Finally, the participants were asked to reflect on their co-authoring experiences and to suggest any other activities that would aid students (research supervisors' response) or themselves (students' response) in becoming proficient science writers (Appendix G).

Several activities and processes were found to be common across all co-authorship teams, including aspects of planning, drafting, and revising. Habits of mind, beliefs about the nature of science, and abilities to communicate the big ideas of science were evident in these activities and processes. Elements of scientific and writing expertise, facets of enculturation into scientific research and discourse communities, academic civility, and the dynamics of collaborative groups also were found. Graduate and post-graduate students' beliefs about science and the role of science writing agreed with those of their graduate supervisors. Findings of this study indicate that co-authoring a research report is an authentic and meaningful learning experience that helps students learn to write like scientists.

Discussion

Findings generated in this study lend support to those of other researchers who studied graduate students engaged in co-authorship with their research supervisors (Belcher, 1994; Chaopricha, 1997; Dysthe, 1999; Prior, 1994, 1995). Co-authorship of research reports in this study provided an opportunity for a cognitive apprenticeship in science writing. Students who partook in this writing experience gained first-hand, authentic knowledge about writing in science. They addressed science concerns, discourse issues, metacognitive awareness, and executive control on an as-needed basis when they encountered authentic problems. They also became further inculcated into their respective disciplinary communities because (1) they had the opportunity to submit to and, in some instance, publish their scientific research results in highly regarded peer-reviewed journals, and (2) during the review and revision of texts, they were afforded a chance to demonstrate their burgeoning scientific expertise.

Several activities and processes such as outlining, drafting, and revising were common across all writing teams. The research supervisors and students could be considered modern, evaluativist scientists who possessed habits of mind such as curiosity, openness, skepticism, and mindfulness, and thus were most likely to ascribe to a point of view about the nature of science that anticipated different interpretations of experiences, events, and data, but required these claims be verified against evidence and augmented with established science ideas. The participants shared beliefs about good science writing. The quality and worth of the science to be reported was central to their decision to start the writing process and to their selection of a target journal and audience. These evaluativists did not fully utilize the language of constructivism. They accepted that writing increased clarity, enhanced the arguments, and improved understanding, but credited the evidence for any drastic changes in conception of the underlying science ideas.

Research supervisors demonstrated academic civility and offered their students excellent enculturative opportunities: They were supportive, trustful, and respectful of their students, and they did not abuse their power. Students also respected and trusted their supervisors; they deferred to their supervisors' academic position at times, but they were not afraid to put forward new ideas and become the expert in the group when appropriate. Numerous examples of the changing mantle of expert were evident when talk turned from a discussion of the general domain knowledge held by the research supervisor to a discussion of the specific procedural knowledge and data details held by the graduate or post-graduate students. None of the participants shied away from the intellectual tension often inherent in vigorous academic debate. The participants showed themselves to be discerning and progressive learners who wanted to constantly push the boundaries of knowledge in their fields. Clearly, they did not simply accumulate knowledge: they took risks and engaged in the jump-shift progression of knowledge, critical thinking, strategies, and metacognition intrinsic to the careers of expert scientists.

Indeed, none of these findings is especially surprising. The research supervisors and students in this study were among the brightest and best that contemporary science has to offer. The convergence of beliefs and similarity of processes obvious in this study is expected in the selective research groups developed by senior scientists. It would be folly to assume anything but exemplary and compatible behaviour from these individuals. The research group is a microworld of academia in which the members provide mutually beneficial and complementary abilities. The dynamics of these two research cultures differed on the surface but were driven by the same desires and motives. All writing- team members realized they were involved in 'real' science, near the leading edge of discovery.

The most interesting finding surrounds the pervasive influence of audience and journal readership in these writers' decisions. Klein (1999) argues that in the backward search interpretation of writing, expert writers "elaborate rhetorical goals of a writing task to accommodate the interests and knowledge of their audience, the personae they wish to project and the formal characteristics of the required text" (p. 243). Irrespective of their references to 'dumping their results onto paper,' which could be associated with Klein's spontaneous utterance hypothesis, or starting with figures or tables and crafting a detailed story around them as a research report, which could be associated with Klein's forward-search and genre interpretations, all of these writers demonstrated the ability and desire to transform their findings so as to persuade select audiences about knowledge claims, which is Klein's backward search incarnate. These transformations filled voids in existing knowledge through the construction of new ideas, and provided a point of departure for further scientific endeavour.

Anthony, Johnson, and Yore (1997) indicated that no single approach to writing was used in a lengthy text. This study underscored that finding. Nonetheless, in considering these writing teams, by far the most prevalent and arguably most valuable approach was the backward search. For instance, in the case of Alistair, Alexander, and Ryo (AT#4), the writing team chose to present their results in a research report format. Alexander then took the lead and composed the paper to appeal to a fairly specific audience of experts in the team's field. However, when the team decided to target a different and broader audience in Nature, they found it necessary to revisit their rhetorical goals and rewrite the piece to appeal first to the journal editors and reviewers and second to the more diverse journal readership. Alexander found this process somewhat difficult because he believed that the science, not the writing, was foremost in the team's work. He did come to appreciate the experience, and he became convinced that adopting a different style of writing would not compromise his science but simply help him transform his results so that they would appeal to a broader audience

Certainly the research supervisors' dedication to their science and their almost obsessive preoccupation with journal selection transcends a simple desire to augment their publication records. These two research supervisors are exceptional mentors, for they have given their students much more than a tutorial in how to publish. They have given them invaluable lessons in becoming consummate science writers. They have shown their students the rhetorical power of writing in science, and they have emphasized, through their actions and words, the essential roles that metacognition plays in science writing, and that writing plays in the construction of new science knowledge.

Comparison of the findings in this study to those of Chaopricha (1997) show similarities and differences. Students in both studies benefited from the draft-revision methods, in terms of writing, critical thinking, and metacognition. However, in this study, discussions of rhetorical goals, specifically audience and journal selection, yielded the most interesting results, while in the Chaopricha study, the dimensions of revision, including revision and negotiation of meaning were most evident. These differences may have resulted because of the difference in the lengths of the two studies, Chapopricha's students were followed over a three-year period, while students in this study were followed for only five months, and the difference in the levels of experience of the students: all of Chaopricha's students were in doctoral programs, while three of the students in this study were post-doctoral fellows.

Implications for Future Research

Bazerman (1988) described the need to consider the context within which a text is constructed. "[T]he rhetorical gist of entire texts evoked the larger framework of meaning within the active disciplines. That is, I couldn't see what a text was doing without looking at the worlds in which these texts served as significant activity." This study provides but a glimpse of the worlds of and the interface between the expert science writer and the novice science writer. Many more processes inherent in these worlds could be studied if the researcher were an integral part of the laboratory or research group. A longitudinal, ethnographic study would provide an opportunity to see the changing interactions between research supervisors and graduate or post-graduate students, and to watch the students develop and become science writers and science constructors over the course of their graduate careers. This type of study would provide not only a series of manuscripts for analysis, but also important insights into the culture of the group and the effect of writing on laboratory work or doing science. In this study, for instance, Rayne was nearly ready to write her results when she and Cotton decided they needed to return to the laboratory to do further experiments which would address the data voids discovered in the early wiring stage. The question here would be, what, if any, effect did the planning and outlining activities have on Rayne's conception of inquiry and the target science, and her approach to the subsequent experiments?

A broader study comprising different disciplines or even several different laboratories within two disciplines would provide a greater basis for comparison among activities, processes, and beliefs. Random selection of research supervisors for inclusion in the study would provide comparisons among groups and potentially increase generalizability. However, a researcher undertaking this type of study would be limited in his or her reporting of results, since stellar and not so stellar examples of mentorship can be clearly identified by their disciplinary specialties and resulting publication titles. As well, academic science and academic science writing does not always progress according to schedule. Hence, science writing moves at its own pace, irrespective of the thoughtful intentions and excellent design of the scientist.

Implications for Practice

This study points to the value of situating writing activities in authentic settings. Taking the terminology of Lave and Wenger (1991), the student writers' participation was peripheral, because they were not yet fully accepted members of the discourse community. It also was legitimized, because the students' research and writing abilities were highly valued by their supervisors and ultimately resulted in their joining a co-authoring team. Thus to divorce technical writing instruction from authentic practice, at least at the graduate level, would effectively eradicate the benefits of situated practice. When asked if they believed a technical writing course would have been valuable in their work, most of the participants in this study replied that it would be for those students who had not previously written a paper. Yet the course would have to meet specific needs. Rayne, who vehemently supported a technical writing course, spoke of "publication worthy" science and science writing, indicating that a generic technical writing course would not be sufficient. Writers at the graduate and post-graduate level require courses or learning opportunities that not only give them general instruction in writing, but also familiarize them with the requirements of the disciplinary discourse community they aspire to, and function to facilitate their apprenticeship as expert science writers.

Research has pointed to the benefits of including authentic writing experiences in technical writing courses (Anderson, et al, 1990; Artemeva, et al, 1999; Caffarella & Barnett, 2000; Foertsch, 1995; Harris, 1990; Smith, 1995; Yore, 2000). The pertinent question is: Who should take the lead in such a course? Ideally, instruction in technical writing would take advantage of the discourse writing knowledge and metacognition of a skilled technical writer and the domain knowledge and metacognition of a scientist. Unfortunately, this marriage of talents, knowledge, and metacognition is rarely seen in one individual. Indeed, curriculum planners would be more likely to find scientists who have excellent writing skills -- Cotton and Alistair are but two examples – than technical writing instructors who have extensive science domain knowledge. The challenge then is to seek ways to facilitate collaborative teaching of scientific writing in authentic circumstances. This study suggests that the co-authoring of a research paper could provide an opportunity for further research on this collaboration.

Concluding Remarks

This research provided insight into graduate and post-graduate science students' experiences in writing. It brought to light activities and processes that are effective in helping students become proficient writers in and of science, especially those associated with rhetorical goals and knowledge transformation. The writers in this study learned how their participation in co-authoring could help them select appropriate journals, address audience needs, build knowledge, and inform their scientific practice. Further study in this area could include longitudinal, ethnographic studies of co-authorship and collaborative teaching of scientific writing in authentic circumstances.

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APPENDIX A: LETTER OF CONSENT

You are invited to participate in a study entitled *Learning to Write like a Scientist: Co-authorship as a Vehicle for Enculturation in Two Post-graduate Science Programs* that is being conducted by Marilyn Florence. Ms. Florence is a graduate student in the department of Curriculum and Instruction at the University of Victoria, and you may contact her if you have further questions by calling 475-6436 or by e-mail: marilynf@uvic.ca.

This research is part of the requirements for a M.A. in Science Education, and it is being conducted under the supervision of Dr. Larry D. Yore. You may contact Dr. Yore at 721-7770.

The purpose of the research is to determine how students in post-graduate science programs learn to write like scientists, thus facilitating entry into their respective disciplinary communities. The study will focus on a single enculturation process – the co-authorship of research documents. The central research questions are:

- What writing experiences and beliefs about writing do science students bring to their post-graduate programs?
- What are the activities and processes inherent in the co-authorship of research documents?
- How does co-authorship help the student become an expert science writer?

This research will provide insight into post-graduate science students' experiences in writing. It will bring to light those activities and processes that prove effective in helping students become proficient writers in and of science. This information will inform and aid curriculum planners in the design of technical/science writing courses for post-secondary institutions.

You are being asked to participate in this study because:

1. *Student: you have been identified by your graduate supervisor as a current or future co-author of a research document (scientific paper, poster, article, etc.).*
2. *Faculty: you have expressed a keen interest in and commitment to mentoring students in science writing.*

If you agree to voluntarily participate in this study, you will be asked to complete a questionnaire (students only); be observed and audio-taped in meetings regarding co-authored documents (writing projects); submit working drafts of writing projects to Ms. Florence for analysis; and partake in occasional discussions about the ongoing writing projects. As well, upon completion of these activities, you will be:

1. Student: presented case summaries and, in semi-structured interviews, asked to validate the findings, and offer comments both about your

experiences and your perceived self-images as expert science writers; and

2. Faculty: presented gist summaries of the findings and asked to submit brief written feedback on your co-authorship experiences.

The inconvenience to you will be minimal. There are no known or anticipated risks to you by participating in this research.

Your participation in this study is strictly voluntary. If you do decide to participate, you may withdraw at any time without any consequences or any explanation. If you do withdraw from the study, your data will be destroyed unless you approve of its use in the study.

For the purposes of confidentiality, you are requested to keep the identity of your writing partner in confidence. I will use pseudonyms in reporting my findings; however, your co-author will know your identity. As well, some details related to the subject and nature of your research work may appear in these findings and may allow you to be identified. Thus I cannot guarantee you complete anonymity. I will make every attempt to treat your comments with sensitivity so as to not in any way compromise your relationship with your supervisor (if your are a graduate student) or student (if you are a faculty supervisor).

Your confidentiality and the confidentiality of the data will be protected by making the questionnaires, documents, tapes and transcripts available only to the investigator. These data shall be kept in a locked cabinet located in MacLaurin A549.

Data from this study will be shredded upon successful completion of my thesis and oral defence. It is anticipated that the results of this study will be shared with others in my thesis and oral defence.

In addition to being able to contact the researcher [and, if applicable, the supervisor] at the above phone numbers, you may verify the ethical approval of this study, or raise any concerns you might have, by contacting the Associate Vice President Research at the University of Victoria (250-721-7968).

Your signature below indicates that you understand the above conditions of participation in this study and that you have had the opportunity to have your questions answered by the researchers.

____________________________ _____________

Participant Signature Date

A COPY OF THIS CONSENT WILL BE LEFT WITH YOU, AND A COPY WILL BE TAKEN BY THE RESEARCHER

APPENDIX B: SCIENCE WRITER QUESTIONNAIRE (PROFESSOR)

Thank you for taking the time to complete this questionnaire. The questions are open-ended and are designed to provide much of the information we need; however, if you volunteer, we will use a personal interview to clarify and expand upon your answers.

Section #1: Your background

1. What is your educational background (colleges/degrees)?
2. What science-related positions have you held (include technical, professional, post-doctoral, and professorial), and for what period of time?
3. For what journals or other publications do you most often write? Please (if possible) attach one or two samples of your writing.

Section #2: What do you consider good science writing?

4. What scientific magazines/journals do you regularly read? Please indicate which publications you read for professional reasons [mark with a (1)], and which you read for pleasure [mark with a (2)].
5. What do you consider to be the characteristics of a well-written scientific article?
6. Based on your perception of good science writing, do you judge material from a peer-reviewed journal differently than you judge material from the popular press (newspapers, *Macleans*, etc.)? Please explain.

Section #3: What type of writing do you do?

7. "I use the following written forms of communication [writing types]…"

1: Never used
2: Infrequently used (a few times each year)
3: Occasionally used (several times per month)
4: Frequently used (several times per week)
5: Daily

Writing types					
Journal research article	1	2	3	4	5
Journal review article	1	2	3	4	5
Commentaries (research journals)	1	2	3	4	5
Book reviews (research journals)	1	2	3	4	5
Letters to editor (research journals)	1	2	3	4	5
Abstracts	1	2	3	4	5
Contract research reports	1	2	3	4	5
Posters	1	2	3	4	5
Seminars/talks	1	2	3	4	5
Grant applications (peer reviewed)	1	2	3	4	5
Grant applications (private foundation)	1	2	3	4	5
Operational and procedural manuals	1	2	3	4	5
Lab notebook/field notebook	1	2	3	4	5
E-mail dialogues with colleagues (related to your research)	1	2	3	4	5
Lecture notes	1	2	3	4	5
Web/electronic conferencing with students	1	2	3	4	5
Short articles/columns for non-science publications	1	2	3	4	5
Letters to the editor (popular press)	1	2	3	4	5
Other ____________________	1	2	3	4	5

8. Do you consider all of the writing (question #7) you do to be scientific? Please explain.

9. For those writing types you consider to be scientific, how do you ensure that the science ideas are accurate and understandable?

10. When you write, do you identify your audience/readership? How does this identification affect the way you write (i.e. the level of technical language, formality, length and so on)?

11. Do you have a general process (or strategy) that you use when you write? Does this process differ depending on the medium for which you are writing, for example, a journal versus a magazine versus a letter to the editor?

12. Does writing help improve your understanding of your work? Please explain.

Section #4: In the following questions, we are looking for specific details about the processes you use when you write.

13. How do you decide what to write about (purpose, topic, and contents)?

14. Do you use an outline; if you do, how detailed is it?

15. Does your planned purpose and design ever change during the writing process? If so, how?

16. Do you do research on the topic before and/or during writing (library reference work, etc. NOT BENCHWORK)?

17. Do you revise? If so, when, and how often?

18. Do others edit, offer suggestions for revision, or provide content feedback on your written product?

19. How do you check your style, grammar, spelling, and punctuation?

20. Do you use the services of a technical editor before submitting your writing? If so, for which writing types (see question 7)? If not, why not?

21. How do you go about addressing referees' suggestions about content and writing style?

Request and Consent

I would be willing to participate in the follow-up interview. The semi-structured interview will take 20 to 30 minutes. I understand the interview will be designed to probe, clarify, and elaborate my responses to the questionnaire. The interview will be tape-recorded and the tapes will be securely stored and destroyed once they are analyzed. Furthermore, the results of the questionnaire and interview will be kept anonymous and confidential, and all reported results will be grouped by commonalities of the respondents (research scientist, area of science, audience). I reserve the right to withdraw at any time and to refuse to answer any question. (Larry D. Yore, Professor, 721-7770).

________________________ ________________________

Name Date

________________________ and ________________________

Telephone E-mail

____

Possible time for interview

Thank you for your time and co-operation.

APPENDIX C: SCIENCE WRITER QUESTIONNAIRE (STUDENT): PART I

Thank you for taking the time to complete this questionnaire. The questions are open-ended and are designed to provide much of the information I need to establish your background; the type of writing you have done; and your beliefs about writing; however, I may contact you for clarification on some points.

Section #1: Your background

1. What is your educational background (colleges/degrees)?

2. What science-related positions have you held (include technical, and professional), and for what period of time?

Section 2: What types of writing do you do?

3. "I use the following written forms of communication [writing types]…"

1 *Never used*
2 *Infrequently used (a few times each year)*
3 *Occasionally used (several times per month)*
4 *Frequently used (several times per week)*
5 *Daily*

Writing types					
Class research papers	1	2	3	4	5
Lab reports	1	2	3	4	5
Lab notebook/field notebook	1	2	3	4	5
Journal research article	1	2	3	4	5
Journal review article	1	2	3	4	5
Commentaries (research journals)	1	2	3	4	5
Book reviews (research journals)	1	2	3	4	5
Letters to editor (research journals)	1	2	3	4	5
Abstracts	1	2	3	4	5
Contract research reports	1	2	3	4	5
Posters	1	2	3	4	5
Seminars/talks	1	2	3	4	5
Grant applications (peer reviewed)	1	2	3	4	5
Grant applications (private foundation)	1	2	3	4	5
Operational and procedural manuals	1	2	3	4	5
E-mail dialogues with professors, other students (related to your research)	1	2	3	4	5
Lecture notes	1	2	3	4	5
Web/electronic conferencing with professors, other students	1	2	3	4	5
Short articles/columns for non-science publications	1	2	3	4	5
Letters to the editor (popular press)	1	2	3	4	5
Other ____________________	1	2	3	4	5

4. Do you consider all of the writing (question #3) you do to be scientific? Please explain.

5. For those writing types you consider to be scientific, how do you ensure that the science ideas are accurate and understandable?

6. Please list your publications (sole or co-authored). You may attach a list or refer to a webpage where the publications are listed.

Section #3: What do you consider good science writing?

7. What scientific magazines/journals do you regularly read? Please indicate which publications you read for professional reasons [mark with a (1)], and which you read for pleasure [mark with a (2)].

8. What do you consider to be the characteristics of a well-written scientific article?

9. Based on your perception of good science writing, do you judge material from a peer-reviewed journal differently than you judge material from the popular press (newspapers, Macleans, etc.)? Please explain.

APPENDIX D: INTERVIEW WITH "COTTON," PROFESSOR, BIOCHEMISTRY & MICROBIOLOGY, AUGUST 17, 2000

1. Re: popular press

People are more and more interested in exotic diseases like Nile fever, AIDS, etc. Based on your experience, how well do the popular press and news releases help lay people understand new science ideas?

2. Re: the internet

Do you use the internet as a research source? How do you judge the quality of the materials on the internet?

3. Re: definition of science

Could you describe your definition of the science (provide 3 examples if necessary)?

4. Re: writing a paper/process

You describe your strategy for writing a research report as plan overview, write easy bits, the results, introduction, discussion, references and abstract. When you co-author an article, do you use this same general procedure? Is this the same with co-authors at a distance? How do you decide what the purpose is? How do you split the tasks among co-authors? How do you sort out differences? Do unexpected results or ideas ever surface and how do you handle them? How do you make revisions? What happens if the referees have a different interpretation or explanation from the authors? How do you resolve this conceptual conflict?

5. Does the process apply to science writing in general and to text forms other than "research reports"?

6. Re: importance of audience

Audience is an important factor in your science writing of chapters, articles and research reports. Who are some of your audiences? Who is the most enjoyable audience? Most difficult audience?

7. Re: building understanding through writing

You said writing reveals "holes" in your thinking. Does writing help your understanding in any other ways?

8. Does co-authoring with your research team help build understanding -- like your discussions at coffee break? Can you provide any examples of this construction process?

APPENDIX E: INTERVIEW WITH "ALISTAIR," PROFESSOR, EARTH & OCEAN SCIENCES, AUGUST 15, 2000

1. RE: Non-science audience

Your article in the faculty newspaper was an interesting example of "crossing borders" to a non-science audience. How did this differ from your normal science writing?

2. Re: importance of audience

Audience is an important factor in your science writing. Who are some of your audiences? Who is the most enjoyable audience? Most difficult audience?

3. Re: popular press

Based on your experience, how well do the popular press and news releases help lay people understand new science ideas?

4. Re: the internet

Do you use the internet as a research source? How do you judge the quality of the materials on the internet?

5. Re: definition of science

Could you describe your definition of the science (provide 3 examples if necessary)?

6. Re: writing a paper/process

What general procedure did you use when you wrote the paper -- title given. How did you decide what the purpose was? How did you split the tasks among co-authors? How did you sort out differences? Do unexpected results or ideas ever surface and how do you handle them? How do you make revisions? What happens if the referees have a different interpretation or explanation from the authors? How do you resolve this conceptual conflict?

7. Does the process apply to science writing in general and to text forms other than "research reports"?

8. Re: building understanding through writing
You mentioned that writing a "review article" helps you build new understanding. How does this happen? Does the same thing happen while writing a research report?

APPENDIX F: STUDENT QUESTIONNAIRE PART II (VIA E-MAIL)

1. When you write, do you identify your audience/readership? How does this identification affect the way you write (i.e. the level of technical language, formality, length and so on)?

2. Do you have a general process (or strategy) that you use when you write? Does this process differ depending on the medium for which you are writing, for example, a journal versus a letter to the editor?

3. How do you decide what to write about (purpose, topic, and contents)?

4. Do you use an outline; if you do, how detailed is it?

5. Does your planned purpose and design ever change during the writing process? If so, how?

6. Do you do research on the topic before and/or during writing (library reference work, etc. NOT BENCHWORK)? Do you use the internet to do research?

7. Do you revise? If so, when, and how often?

8. Do others edit, offer suggestions for revision, or provide content feedback on your written product?

9. How do you check your style, grammar, spelling, and punctuation?

10. Do you use the services of a technical editor before submitting your writing?

11. I have attached a document with three images of the nature of science.

<u>Image A</u>

> This view of science suggests that science knowledge is developed through observations, measurements and plausible reasoning. Facts are accumulated by making observations and measurements, and these data are generalized to form a big idea (science claim), or intellect is used to produce rational speculation (science claim). This view of science proposes that the theory or concept is generated by inductive reasoning using the evidence gained through a series of observations. Deductive reasoning occurs when a general rule exists and is used to predict or explain other events and observations. Scientific knowledge, according to the absolutist view, is a collection of truths that is unchanging. The scientific method is a single, universally accepted process. The process itself provides validation to the knowledge claims, as this process is controlled and scientists are objective.

Image B

This view of science proposes that science knowledge is a temporary explanation that best fits the existing evidence and current thinking. Science knowledge claims develop with the aid of a hypothesis (causal statement) and data that are collected which support or refute the hypothesis. Hypothetico-deductive reasoning relies on the absence of refuting evidence and the presence of confirming evidence as support for a hypothesis. Since scientists have preconceptions about the outcome of an investigation, most evidence the scientist would likely collect would support the existing hypothesis rather than refute the hypothesis. Science knowledge claims in the evaluativist view are believed to be temporary and are open to repeated evaluation. The scientific method, within this view of the nature of science, is not bound by a single set of steps.

Image C

This view of science knowledge proposes that people construct explanations in the context of their own personal beliefs. The different interpretations and explanations of the natural world are expected and considered of equal value. The relativist view of science does not question, evaluate, or judge divergent interpretations and explanations, since one explanation cannot be judged as more valid than another explanation because different interpretative frameworks were used (all are of equal merit). Science knowledge claims are viewed as individualistic and a product of unique socio-cultural contexts.

Which image do you think best describes your definition of science? Please explain.

APPENDIX G: CULMINATING QUESTIONS FOR PARTICIPANTS

Research Supervisors

1. How was this mentorship experience similar to ones in the past? How was it different?

2. Did being observed affect your interactions with your student(s) during the co-authorship process? If so, how?

3. Did you see changes in the student's writing during this co-authorship experience? Critical thinking? Their knowledge about and control of writing?

4. Do you believe that you were always the expert during the co-authoring? Please elaborate.

5. What do you think was most valuable to the student in this co-authorship process? What was most valuable to you?

6. Where there any times/cases when your co-author(s), you, or all of you made new insights into the target science concepts because of the authoring, the struggle to represent your ideas, or to revise the structure, clarity, or organization of your writing?

Students

1. Do you believe this co-authorship process affected your writing? Your critical thinking? Your knowledge about and control of your writing?

2. Did writing this paper help you better understand your research? If so, how?

3. Did writing this paper help you develop clearer expectations about writing for this science journal and audience? What did you learn specifically?

4. Where there any times/cases when your co-author(s), you, or all of you made new insights into the target science concepts because of the authoring, the struggle to represent your ideas, or to revise the structure, clarity, or organization of your writing?

5. How did this experience compare with other co-authorship experiences you have had? How would you describe your role in this experience?

6. Would a formal course in scientific writing have helped you in completing this paper? Would such a course be valuable for other graduate and post-graduate students?

7. Did being observed affect your interactions with your research supervisor during the co-authorship process?

8. What do you think was most valuable to you in this co-authorship process? What was most valuable to your research supervisor?

APPENDIX H: SAMPLES OF RESPONSES E-MAIL INTERVIEW

SAMPLE #1: Non-native English speaker

1. Do you believe this co-authorship process affected your writing? Your critical thinking? Your knowledge about and control of your writing?
I suppose "this paper" indicates [another participant's] paper.
I believe this experience is very beneficial to me. While I am reading, I realized that what kind of expressions or description gives readers impression that the results are not very robust or not very trustworthy. It makes me realize that it is very important to make main story clear rather than details.
2. Did writing this paper help you better understand your research? If so, how?
I read very carefully and tried to be critical as well while I was reading. In that sense, it helps me to understand related my research.
3. Did writing this paper help you develop clearer expectations about writing for this science journal and audience? What did you learn specifically?
Disclosure of uncertainties is very important, but extra attention damages the paper. Main story and simple flow of the story is extremely important. Also, uniqueness and impact of the paper gives good impression.
4. Where there any times/cases when your co-author(s), you, or all of you made new insights into the target science concepts because of the authoring, the struggle to represent your ideas, or to revise the structure, clarity, or organization of your writing?
It happened a lot during the research but not from writing. It happened not because I am a co-author, but I am a co-author because it happened.
5. How did this experience compare with other co-authorship experiences you have had? How would you describe your role in this experience?
I don't think there is much difference compared to the previous one. The previous one has a large number of co-authors, so I focused on only my technical part. This time I focused on the main story and critical view for the paper, that is, [the] science part.
6. Would a formal course in scientific writing have helped you in completing this paper? Would such a course be valuable for other graduate and post-graduate students?
I have never had that kind of training. But I am very interested in as especially English is not my first language.
7. Did being observed affect your interactions with your research supervisor during the co-authorship process?
No
8. What do you think was most valuable to you in this co-authorship process? What was most valuable to your research supervisor?
To me, I learned a lot how to write and organize writing to this "special" journal (Nature) More importantly, the fact that UVic group is participating in the millennial scale climate variability research is the most valuable to my supervisor and me, I think. Particularly, in [this] politically influential journal (Nature).

SAMPLE #2: Native English speaker

1. Do you believe this co-authorship process affected your writing? Your critical thinking? Your knowledge about and control of your writing?

Writing: With this paper, yes, in the sense that I would not have targeted this journal, and the style will have to be different for it. For past papers, yes, in that other authors noticed problems (content or style) that I had missed; it was all constructive.

Critical thinking: Perhaps, in that I know my weaknesses a bit better, and a bit more about how to write a paper.

Knowledge about my writing: I guess, in that I know my weaknesses better.

Control of writing: No. In all cases and in the past they have been my papers. The co-authors have always been suggestive rather than authoritative in comments, and some I have not implemented, although I have always explained my rationale to them of course.

2.Did writing this paper help you better understand your research? If so, how?

Definitely. I find when a research idea comes up you know how it places in the general scheme. When doing the research however it is very easy to get rather focussed on narrow issues, and in the end you end up with solid results on branches of what you were originally planning to do. So writing the paper forces you to reconsider where this all fits in to the general field.

3. Did writing this paper help you develop clearer expectations about writing for this science journal and audience? What did you learn specifically?

Since I am only beginning to write, I cannot really answer this. But I can say that I am sure that it will. I have never written for such a general science journal before, so it will be a challenge to keep the technical level down without washing out the science.

4. Where there any times/cases when your co-author(s), you, or all of you made new insights into the target science concepts because of the authoring, the struggle to represent your ideas, or to revise the structure, clarity, or organization of your writing?

Definitely. When you come with an idea for research it tends to be: "no one has done this before, and any results will be useful." Once you get the results, it tends to be "okay, so which of these results here are more important, surprising, and/or coherent for a story." Writing forces me to focus.

5. How did this experience compare with other co-authorship experiences you have had? How would you describe your role in this experience?

In the past I have always co-authored with my supervisor and one other person. They have never been persistently looking over my shoulder, demanding updates, or flooding me with suggestions. However, this time (a paper with my supervisor) I have definitely been given more free rein.

6. Would a formal course in scientific writing have helped you in completing this paper? Would such a course be valuable for other graduate and post-graduate students?

I do not think it would have helped me here. It could perhaps be useful for other students, but I think generally this is covered in other courses through term projects, for example. I think that this kind of writing is good training. The scientific style of writing is designed to be rather [straightforward] which is why people with little command of English can write good, clear scientific papers. I think the biggest problem is a matter of people not putting the effort into polishing a paper, not thinking that this is as important as the results.

7. Did being observed affect your interactions with your research supervisor during the co-authorship process?

Not really. Meetings tended to be more formal only in the sense that they were actually called "meetings." Otherwise we would have tended to break it into more frequent chats of a few minutes duration. I don't think this changed anything though.

8. What do you think was most valuable to you in this co-authorship process? What was most valuable to your research supervisor?

Me: Learning to write for a more general journal. Getting a paper published (the Scientific currency).

Supervisor: Getting a paper published.

APPENDIX I: SAMPLE INTERPRETATION CHART

Proposition #1: Members of a laboratory, and specifically members of these co-authorship teams, would be expected to demonstrate habits of mind conducive to doing science, and to writing, revising, and submitting scientific papers for publication.

Principle / *Team*	Curiosity	Scepticism	Openness	Mindfulness	Mental effort	Risk taking
Biochemistry Team #1						
Atmospheric Physics Team #1						
Atmospheric Physics Team #2						
Atmospheric Physics Team #3						
Atmospheric Physics Team #4						

VITA

Surname: Florence Given Names: Marilyn Karen

Place of Birth: Camrose, Alberta, Canada

Educational Institutions Attended:

University of Victoria	1999 to 2001
University of Alberta	1984 to 1987

Degrees Awarded:

B.Sc.in Agriculture (with distinction)	University of Alberta 1987

Title of Thesis:

Learning to Write like a Scientist: A Study of the Enculturation of Novice Scientists into Expert Discourse Communities by Co-authoring Research Reports

Author [redacted]

Marilyn Karen Florence

September 18, 2001