CHEMISTRY ELEVEN: A Hands On Approach

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B.Sc., University of Victoria, 1971

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

MASTER OF ARTS

in the Department of Social and Natural Sciences

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ABSTRACT

This study explored the effects of two instructional treatments on two comparable groups of Chemistry 11 students in a semi-rural town in British Columbia, Canada. The purpose of the study was to explore the effects on students of teaching Chemistry 11 using a variety of non-traditiontal - hands on - teaching strategies as compared to using more traditional teaching strategies.

The central foci of the reseach questions were academic test scores, cognitive development, attitude toward science, self concept and student interest/ enjoyment. Quantitative data were collected on both the experimental and control groups on a pre-treatment/ post-treatment schedule while qualitative data was collected on each group on an on-going basis over the course of the study.

Results of the study supported the hypothesis that hands on activities may:

1. contribute toward a significant increase in cognitive development, and
2. enhance student interest and enjoyment in Chemistry 11.

Student self-perception and student attitude toward science showed insignificant longitudinal gain among both groups over the course of the study.

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Chapter 1

Statement of Problem: Purpose, Significance and Limitations of the Study

Introduction

The British Columbia Ministry of Education offers four traditional sciences at the grade 11 level; Biology 11, Earth Science 11, Chemistry 11, and Physics 11. These are non-compulsory courses taken by some 65% of secondary students.

Experience with the British Columbia Chemistry 11 course since 1981 has suggested that certain teaching strategies enhance student interest and enjoyment. A concern of science teachers must be that student interest and enjoyment be nurtured, in order that chemistry be viewed as relevant in our technologically oriented society and be pursued by the young students in our schools as a future career option.

The Purpose and Context

The purpose of this study was to explore the effects on students of teaching Chemistry 11 using a variety of non-traditional teaching strategies. Results were divided for analysis into two realms:

1. a subjective realm concerned with student interest and enjoyment, and;
2. an objective realm concerned with academic success.

Subjective results used to measure interest and enjoyment consisted of data from three sources:

1. classroom observations/anecdotal records;
2. the Harter Self-Perception Profile for Children (Harter, 1985); and
3. British Columbia Ministry of Education School Science Likert Scale designed to measure student attitude toward science.

Objective results used to measure scholastic achievement consisted of data from two sources:

1. comparisons of marks on student achievement tests; and,
2. the Arlin Test of Formal Reasoning (Arlin, 1987) designed to measure cognitive development.

Significance of the Study

The teaching strategies used in this study were associated with what was currently described as good science teaching practice in that they attempted to:

- link unit topics with everyday experience,
- directly involve students as active participants,
- involve students in open-ended and less predictable experiences than found in traditional laboratory activities,
- create unusual in-class discussion and enjoyment.

Traditional chemistry teaching strategies have had a range of effects on students; and although the traditional laboratory investigation has often been touted as providing students with hands on scientific experiences, it was the authors's experience that chemistry "labs" often served poorly in this regard and were typically perceived by chemistry students as boring, irrelevant, too difficult, too easy or simplistically predictable.

Determining a root cause of the students' perceptions is a daunting and perhaps impossible task, but this author suggests that the instructional strategies used in this study reduced the negative effects associated with traditional chemistry teaching strategies (boredom, irrelevancy, difficulty and predictability) while enhancing positive effects by returning relevancy and enjoyment to the classroom.

Context

The Teacher

The teacher's post-secondary academic background consisted of a Bachelor of Science degree granted by the University of Victoria in British Columbia, Canada, with a major in zoology (physiology focus) and a minor in chemistry (three full-year courses; first year general chemistry, second year inorganic analytical chemistry and second year honours organic chemistry). At the time of this study, he was active in the building trades, had been published, had conducted several education workshops and chemistry "magic shows," and had taught for 12 years at both the junior (grades 8-10) and senior (grades 11-12) levels. His entire teaching experience was at the school where the study was carried out.

The Students

The vast majority of students in this study appeared as optimistic, and were socially adept. They were all white youngsters from middle-class/professional backgrounds. Most came from intact families, though there were exceptions. Few behaviour problems existed among this largely conservative group of students.

The Setting

The setting for this study was a growing semi-rural western Canadian town of 25,000 population. The town enjoys the highest number of hours of sunshine in Canada and is nestled in a beautiful valley between two lakes. This location makes it a tourist haven, and in fact the population doubles during the summer months. The single high school in the town where this study took place also serviced two nearby villages of about 1,000 population each.

The students studied comprised three blocks on a full year or linear system. The total sample size was 68. Forty-seven (47) were in the experimental blocks (n_1=25, n_2=22). The sample size for the control group was 21. The study ran from November 30, 1987 to April 25, 1988 and covered term 2 and most of term 3 in a four-term year. The control group was randomly selected by coin toss. No inquiries were made with regards to average IQ's or other cognitive attributes prior to this selection. The experimental groups were exposed to the non-traditional strategies while the control group encountered a significantly more traditional Chemistry 11 course.

Limitations of the Study

The sample explored, the course content, the teacher and the school structure were factors that limit the generalizability of the findings of this study. The student sample group was optimistic, generally motivated and appeared to enjoy school; few problem students existed. The teacher was energetic and interested and had a good sense of humour which he practised with his three chemistry classes. The school was timetabled on a traditional linear (September-June) format. The school buildings were very well maintained; and while the building was some 35 years old, the chemistry labs were brand new, state of the art facilities. The district obviously practised extensive and continued maintenance and renewal. The district was a destination district and as such it could draw and keep strong teachers. Students enroled in the senior sciences could typically expect to have at least 3 or 4 strong, motivating teachers.

Overview of the Study

The investigation started in November 1987 and ran until late April 1988. Specific chemistry topics covered were: mixtures and separation techniques, kinetic molecular theory, gram molecular weights, the mole concept, naming of compounds, percent mass problems, reaction types, gas laws, stoichiometry, temperature, pressure and heat, heat, solution chemistry, molarity, dilution, and dissociation.

All three groups completed the same academic achievement tests. Moreover, all seven Chemistry 11 blocks in the school had to write both a common traditional comprehensive mid-year examination at the close of second term and a common final examination. Therefore, all classes in the school covered common content, and achievement was measured against British Columbia Ministry of Education learning outcomes. The study utilized three classes of Chemistry 11 students. The three classes taught solely by the investigator had similar attributes in as much as the school practised no explicit streaming policy; sections of courses were created in response to demand and filled on a first come, first served basis after compulsory courses had been timetabled.

Chapter 2

Review of Literature

Introduction

Teachers use curriculum differently (Grossman, 1987; Oberg, 1987; Wilson & Wineberg, 1985). The literature attests strongly to this observation and suggests that a prime goal of teacher education should be the art of bringing curriculum to life. A living curriculum involves engaging students in the classroom in such a way that they become active participants in their own education (Lawson & Renner, 1976; Herron, 1975; Bonnstetter, Penick & Yager, 1983).

The experimental teaching strategies used in this study were examples of different or non-traditional uses of curriculum. Each teaching strategy substituted for a single phase in a traditional instruction-verification-expansion teaching/learning cycle. Consequently, while each strategy was designed to enhance student interest and enjoyment, the differences between each stemmed from the phase substituted (instruction, verification or expansion). Teaching strategies which replaced a traditional instructional phase were designed to provide students with a common set of reference experiences, or context, in addition to providing support and structure for observations which they had made in the real world. Teaching strategies which replaced either a verification or an expansion phase had similar objectives in that each was designed to place students in a situation where they had little choice but to actively participate in a concrete experience which was often of their own design and which served to link either an introductory lesson with classroom experience and prior conceptual knowledge (where a verification phase was replaced) or to link classroom theory and verification with prior conceptual knowledge and classroom theory (where an expansion phase was replaced).

It is important that chemistry teachers use teaching strategies which bring curriculum to life, in order that student interest and enjoyment be nurtured. This introduction suggests that a review of four issues will be of value in setting a framework on which to design and evaluate this study. The issues to be dealt with consecutively by the survey of literature are:

1. literature related to curriculum use,
2. literature related to exemplary teaching strategies,
3. the value of using strategies which are associated with exemplary teaching, and
4. the specific learning outcome domains associated with effective science instruction: knowledge/skill, cognitive development, self-concept, and attitude.

Literature Related to Curriculum Use

Oberg (1987) stated that "subject matter is a variable curriculum resource which can be used to serve various educational ends" (p. 1). Grossman (1987) in a study on the role of subject matter orientation in teaching suggested that two teachers teaching the same course taught in significantly different ways and that the selection of their teaching strategies was associated with their respective orientations to subject matter. Grossman felt that orientation to subject matter was less a matter of what one knew and more a matter of how one knew it. How one knew a subject related directly to one's experiences with the subject, whether it be through formal exposure, informal or a combination of each. In Grossman's study, one teacher was formally imbued in English and was a textbook centred teacher while the other possessed a more eclectic background and was significantly more student centred in her teaching. Wilson and Wineberg (1987) found similar results in their study on the role of disciplinary perspectives in the teaching of American History. Their research compared four novice teachers. They found that "While watching these people learn to teach, it became apparent to us early on that their disciplinary background wielded a strong--and often decisive--influence on their instructional decision making" (p. 2). Steinberg, Haymore and Marks (1986) posited that teachers who had a greater knowledge base in their discipline tended to be more conceptual in their teaching, used applications of knowledge, interrelated concepts, were more abstract and used more problem solving while those with a smaller knowledge base tended to be oriented more toward a rule-based teaching style. Shulman (1985) reported that "the teachers' understanding, transformation, and use of subject-matter knowledge" was a central part of his research (p. 2). Shulman revealed a fascination in the transformation of a teacher's formal academic knowledge gained as a student into faltering attempts to transform that knowledge into a form suitable for teaching. Steinberg, Haymore and Marks (1985) studied the relationship between teachers' knowledge of mathematics and the structuring of mathematics content for instruction. They reported marked distinctions between four student teachers with different academic backgrounds and abilities in how they perceived and taught specific content and concepts. The Search for Excellence Science Program (NSTA, 1983), was based on the assumption that teachers used curriculum differently and with varying degrees of success. Bonnstetter, Penick and Yager (1983) observed that their work "should aid in determining what program and teacher characteristics lead to success" (p. 5).

Teachers bring different formal academic backgrounds and life interests to teaching. As a result they teach subject matter knowledge in a variety of ways. In order to make classroom experiences interesting and enjoyable for students, teachers must bring curriculum to life by:

1. linking subject topics with everyday student experience,

2. directly involving students as active participants in their own education,

3. involving students in open-ended and less predictable experiences than are generally found in traditional laboratory activities, and

4. creating unusual in-class interest and enjoyment.

Renner and Grant (1978), in a study of 708 eleventh and twelfth graders from 13 Oklahoma schools found that laboratory experiences maximized the concreteness of difficult concepts in physics and thus made physics more accessible to students. Lawson and Renner (1975) observed that providing concrete experiences with objects and with the ideas of the discipline and actual involvement with the materials and ideas of science allowed students to find out things for themselves. They suggested that science teachers had a vehicle at their command whereby they could do this; the laboratory. They further posited that an effective teacher has three responsibilities in ensuring that students find out something for themselves:

1. The teacher must use his background knowledge and understanding of the structure of a discipline in order to select concepts that will provide a student with a personal, accurate understanding of the discipline (they suggested that textbooks were of little use here).

2. The teacher finds those laboratory investigations which are to be transformed into an inquiry format and which when completed allows students to gain an understanding of the topic at hand (they suggested that textbooks were of no use here).

3. The teacher having transformed laboratory investigations into an inquiry format has to ensure that the necessary materials are available.

Herron (1975) suggested modifications in the approach to teaching chemistry that may ultimately lead to better instruction. Among these were the use of physical models and extensive use of concrete props which modelled abstract concepts. He felt teachers did this now, but not enough; and he observed that without use of these devices, students would tend to simply memorize facts with little understanding.

Bonnstetter, Penick and Yager (1983) generated from their extensive study a list of characteristics of teachers who brought curriculum to life; they stated that teachers in the Search for Excellence study (p. 33):

1. provide a stimulating environment;
2. create an accepting atmosphere;
3. expect different students to achieve differently;
4. put in far more than minimal time;
5. have high expectations of themselves;
6. challenge students beyond ordinary school tasks;

7. are themselves models of active inquiry;
8. do not view classroom walls as a boundary;
9. frequently use societal issues as a focus;
10. work easily with community leaders, administrators, and parents;
11. are extremely flexible in their time, schedule, curriculum, expectations and view of themselves;
12. are concerned with developing effective communication skills;
13. provide systematically for feelings, reflections, and assessment;
14. require considerable student self-assessment;
15. ask questions, expecting to hear new, and often unpredicted, answers;
16. expect students to question facts, teachers, authority, and knowledge;
17. encourage pragmatism;
18. stress science literacy;
19. want students to apply knowledge; and
20. do make a difference.

Pavelich and Abraham (1979) suggested that open inquiry laboratory exercises served to bring curriculum to life since they felt that a guided inquiry/open laboratory format was significantly more realistic in a scientific inquiry sense than traditional laboratory exercises. Their concept of the guided inquiry/open laboratory format included that students were able to design their own experiments and that the instructor or laboratory guide required students to explain why certain things happened. Laboratory reports required that students used observed evidence to back up their conclusions, and in discussion with the instructor, assumptions were challenged and conclusions had to be justified. Shymansky (1977/78) saw the bringing of curriculum to life as constituting activity-centred programs where hands on activities were used and where students were given some decision-making power. Erickson (1984) noted that sustaining good teaching over time required relevancy, particularly to the future, and was a key feature of instruction that would keep curriculum alive for students.

Literature Related to Exemplary Teaching

Teaching strategies associated with exemplary teaching, when practised correctly by the classroom teacher, bring curriculum to life by encouraging "student action, decision making, creativity and excitement" (Bonnstetter, Penick & Yager, 1983, p. 30). Searles and Kudeki (1987) concluded that the outstanding instructor utilized various materials and methods as deemed necessary, was pupil centred and showed creativity and resourcefulness. Further, an outstanding teacher was capable of perceiving and making provision for the varying needs and abilities of individual students and tried to develop self-confidence and motivation in students. Such a teacher was fair, emotionally calm had a good sense of humour and was respected by the students. Ward (1987) observed that even though facts may have been forgotten, the exemplary teacher could create a positive feeling toward a subject which lasted well beyond the years of formal schooling. Ward further reminded teachers to encourage students to detect new details, to talk with students, and use unusual tasks. Typical tasks would be those found in brainteaser sections of magazines or in books like Metamagical Themas (Hofsteader, 1986). Typical examples of unusual task were to measure the total length of thread in a shirt in micrometers or calculate the average number of notes played by a concert grand pianist in a lifetime. Ward (1987) felt strongly that teachers were surrounded in their everyday life by an abundance of scientifically relevant teaching materials. He further observed that teachers must be willing to use open-ended questions for which they may not necessarily have complete answers themselves, in order to demonstrate the ongoing inquiry nature of science. Ward agreed with Einstein's notion that imagination was more important than factual knowledge. Educators must use teaching strategies associated with exemplary teaching to encourage students to think, and to be imaginative; but how does this work in the classroom?

The Exemplary Practice in Science and Mathematics Education Study provided detailed observations on 13 science and mathematics educators and 20 exemplary teachers in schools in the metropolitan area of Perth, Western Australia which illustrated exemplary practice in action (Tobin, Treagust & Fraser, 1988). Exemplary teachers were identified through a peer nomination process, and were observed in the classroom by members of the research team. "Les" was observed some 100 times. The authors observed that misbehaviour was seldom a problem in Les' class. He was an active teacher who endeavoured to match instruction to the needs of individual learners. He used carefully structured questions to elicit student thinking, listened carefully to responses and then developed follow-up activities in response to student needs. Activities were designed to involve students actively throughout his biology lessons. In Les' classes, approximately 15% of class time was spent on individual laboratory activities (non-interactive), 15% on whole class discussion, 35% on small group work and 15% on transition from one activity to another. These time segments allowed students to overtly engage in tasks as well as to interact with other students and with the teacher.

The teachers with whom Les was compared gave far more time to whole class (homogeneous) activities at the expense of small group work and much more time was used in the transition between activities. Weaker students in Les' class participated by reading prepared answers and Les persisted in engaging all of his students during questioning periods by rephrasing his questions until a student could contribute. Les quickly and unobtrusively redirected misbehaving students and brought them back on task. Les' non-exemplary colleagues emphasized learning by rote and the learning of algorithms with little time to develop understanding. Les had an ability to tie together major principles and link them to the students' prior conceptual knowledge. Students in Les' classes had a considerably more favourable view of their actual classroom environment than the comparison group had of its science classes as indicated by results from all dimensions of the Classroom Environmental Scale (CES) (Fraser & Fisher, 1983a). While Les' students perceived a more favorable classroom environment on all dimensions assessed by the CES, these differences were most marked in terms of high levels of Involvement, Teacher Support and Order and Organization.

Fraser and Fisher (1983a) described the Involvement dimension on the CES as the extent to which students showed attentive interest, participated in discussions, did additional work and enjoyed the class. The Teacher Support dimension was described as the extent to which the teacher helped, befriended, trusted and was interested in students and the Order and Organization dimension was described as involving the emphasis placed on students' behaving in an orderly, quiet and polite fashion and on the general organization of all classroom activities.

The remaining dimensions on the CES were Affiliation, Task Orientation and Rule Clarity. On these dimensions the perceptions of Les's students were still more favourable than the perceptions of students in the non-exemplary classes. Affiliation was described as the extent to which students got to know each other, enjoyed working together and helped each other. Task Orientation was described as the extent to which students found it important to stay on topic and to complete assignments and Rule Clarity was described as the extent to which emphasis was placed on clear rules which were understood by students and the consistency with which teachers dealt with rule breakers.

In most cases, laboratory exercises in Les' class began without a prelaboratory discussion and hence forced students to participate in homework. Although the make-up of laboratory groups was chosen in most cases by the students, sometimes groups were changed by Les to attain a more productive working arrangement. A feature of interactive (class/teacher) discussions was that care was taken to relate (link) the laboratory findings to two areas: the text book and prior conceptual knowledge developed from formal education as well as from real life. Student control was successful with a relatively large class size, since students spent appreciable time actively learning or being engaged in stimulating activities generated by a teacher who showed sensitivity, demonstrated a supportive attitude and possessed a strong and ever-expanding knowledge base.

Tobin and Fraser (1988) conducted another Australian study where 13 researchers were involved in observing exemplary teachers and interviewing them and their students. They reported that these teachers:

1. used management strategies which facilitated sustained student engagement,
2. utilized strategies which encouraged students to participate in learning activities,
3. used strategies designed to increase student understanding of science and mathematics concepts, and
4. maintained a classroom learning environment which was perceived as favourable by students.

Furthermore, the students enjoyed the class and liked the teacher as well as the subject matter. In each of the Australian studies, increased student autonomy was a goal. Assignments encouraged individual thought and cooperation when working in groups. The teacher controlled the class by moving around the room and speaking to individuals from time to time as opportunities presented themselves. Unlike the classrooms of non-exemplary teachers, where work "is not demanding, is tedious and has little relevance to the world outside the classroom" (Tobin, Treagust & Fraser, 1988, p. 142), the classes of exemplary teachers were demanding, interesting and relevant. Yager (1983) presented a synthesis of research findings that he felt were signs of crisis in U.S. science education. His areas of concern were that nearly all science teachers used lectures and question and answer strategies which were based on textbook information, that over 90% of teachers were not only content oriented but viewed content as static. Additionally, he observed that the vast majority (90%) of teachers orient their teaching toward a textbook 95% of the time and hence that the students' view of science is limited by the textbook. He felt that laboratory exercises were seldom aimed toward the student finding out things for himself and that the exercises were largely verification of what the student already knew by reading in the textbook or by having been told by the teacher.

Penick and Krajcik (1984) described eight exemplary programs in high school chemistry and while little direct descriptive information was reported about the teachers in the programs, an interesting four-goal cluster indicating the desired state of chemistry education (delivered by teachers) was suggested (p. 5). The goal clusters were:

> 1. Personal Needs. Science education should prepare individuals to utilize science for improving their own lives and for coping with an increasingly technological world.
>
> 2. Societal Issues. Science education should produce informed citizens prepared to deal with societal issues.
>
> 3. Academic Preparation. Science education should allow those students who wish to pursue science academically and professionally to acquire the knowledge needed.
>
> 4. Career Education/Awareness. Science education should make students aware of the nature and scope of science-related fields.

A range of valuable outcomes accrue to students whose teachers use teaching strategies associated with exemplary teaching.

Literature Related to the Value of Exemplary Teaching

Students like having effective teachers. Labonty and Danielson (1987) supported the hypothesis "that if teachers display behaviors considered effective at changing pupil behaviors" (p. 398), they will be the teachers children prefer. This research agreed with an equivalent finding carried out on adult students by Medley (1982). Feldman (1987) found that the use of hands on manipulation of objects in teaching science was highly motivating for her students. The hands on strategies constituted less formal learning among 10 year olds in her study and served to illustrate that science materials and concepts were part of a students' everyday world. She felt that the barrier between the inside of the classroom and the outside was often overemphasized, and that science included much informal learning which took place through a person's entire life and was an ongoing process. Erickson (1974) felt that "the ability to start this learning chain reaction is one of the defining characteristics of a good teacher" (p. 79). Rosenshine (1970) indicated that those teachers who communicated a sense of excitement and enthusiasm saw it returned in the attending behaviour of their students. Allowing for student differences in terms of adapting to different levels of curiosity among students, different levels of academic strength and different levels of interest aided in the development of student self-esteem (Erickson, 1974). Rogers (1983) observed that students learned effectively, enjoy learning the process of learning, became creative and became self-motivated when the teacher was a facilitator who promoted an environment which placed his students in contact with realistic problems as a form of experiential learning. Erickson (1974) corroborated Rogers' observations on self-motivation and stated that "If the substance of the course is worthwhile, well planned, and if the teacher evidences an honest interest in the subject and the students, the problem of motivating students will almost take care of itself" (p. 80). Drew, Olds and Olds (1974) observed that a stimulating classroom aroused student curiosity and generated motivation while off beat ideas sparked student interest. They further noted that true understanding among students was associated with students having been able to invent for themselves in a guiding and nurturing psychosocial setting. Roth (1987) suggested that in order to learn, students had to actively extract information from their environment and construct personal interpretations and meaning. Learning in this sense involved fitting new observations into existing notions or schema (assimilation) or involved changing schema in response to the new experience. Roth indicated the importance of the development of teaching strategies designed to encourage students to construct links relating concepts not only within the same subject but with other disciplines.

Nussbaum and Novick (1982) developed a conceptual change model of learning which was consistent with Roth (1987). It included four important procedural steps that were part of the instructional process:

> 1. initial exposure of students' alternative conceptions through their responses to an "exposing event;"
> 2. sharpening student awareness of their own and other students' alternative conceptions through discussion and debate,
> 3. creating conceptual conflict by having students' attempt to explain a discrepant event; and
> 4. encouraging and building cognitive accommodation and the invention of a new conceptual model consistent with the accepted scientific conception. (p. 195)

Anderson and Smith (1987) stressed several points to consider when designing situations to encourage conceptual change, specifically that students and their initial conceptions must be actively engaged, they must make predictions of outcomes of possible solutions and they must be allowed to verify their predictions.

One of the major directions along which individual development proceeds is toward a state of greater autonomy. "Movement away from the absolute dependence of early infancy and toward the relative independence of adulthood is the universal path along which all persons must travel" (Grolnick & Ryan, 1987, p. 213). Grolnick and Ryan observed that there were in fact natural or inherited tendencies that were to be found in every child, which led him or her in the direction of decreased heteronomy and greater self-direction (Dewey, 1938; Bruner, 1962; Rogers 1983; Piaget, 1971). Teaching strategies associated with excellence in teaching nurtures increased autonomy. Grolnick and Ryan (1987, p. 215) offered a set of six propositions capable of empirical exploration on the potential value of increased autonomy to students. Specifically:

> 1. Autonomy is essential to self-motivation. When autonomy is experienced, motivation, interest and desire of challenge are associated characteristics.
>
> 2. Children develop autonomy, self-motivation and self-regulation to a greater degree under conditions where adults support autonomy.
>
> 3. Emphasis on controlling behaviour and salient use of external pressures and rewards undermines the sense of autonomy, and leads to lower self-regulatory capacities.
>
> 4. Autonomy is essential to self-esteem. Self-esteem develops, that is, only when one's actions and interactions are valued and supported.
>
> 5. The development of autonomy is a transactional process. The more it is supported, the more it obtains. However, the less it is in evidence, the less likely adults are to support autonomy and

> the more likely they are instead to control or enforce compliance.
>
> 6. Autonomy will tend to be exercised under conditions of optimal challenge, but challenges too great or too easy are inimical to its expression.

Grolnick and Ryan (1987) presented strong evidence which supported each of these propositions and further stated that a very powerful argument could be made in favour of increased autonomy solely on the basis of evidence which indicated that it "facilitates actual learning and retention of information"(p. 234). In conclusion, they wrote that "the artful task of teaching and parenting with respect to education is thus one of creating conditions ripe for autonomous assimilation and growth. In short it is the art of instantiating for every child a facilitating environment" (p. 229).

Different teachers use curriculum materials differently. The effective use and integration of teaching strategies associated with exemplary teaching contribute toward effective teaching by creating a psychosocial environment which is conducive to enjoyable learning and which nurtures student interest. The outcomes of effective science teaching must be the development of an independent learner and thinker. Specifically, effective teaching should seek to improve the learners' knowledge and skills in science, attitudes toward science, self-concept and cognitive development.

Learning Outcome Domains

Review of the literature pertinent to the study suggested that a consideration of five specific learning outcome domains would be useful in evaluating this study. The domains were: academic achievement, cognitive development, self-concept, attitude, and student interest/enjoyment.

Academic Achievement

Senior science students who were capable of operating effectively with abstract formal thought attained significantly higher grades than those who operated at the concrete level (Ball & Sayre, 1974; Cantu & Herron, 1978; Goodstein & Howe, 1978; Renner, 1976; Sheehan, 1970).

Ball and Sayre (1974) summarized their study as follows: "Junior and senior high school students may exist at different stages of physical development. We should not penalize these students for something (mental or physical development) over which they have little or no control," p. 336).

Cantu and Herron (1978) stated that "if we are to increase comprehension of science, we must either assist students in their development of reasoning or we must learn to teach so that ideas of science are understood by students who remain at the concrete-operational level" (p. 141). Teachers must determine the cognitive capabilities of their students and design proper learning experiences to match those capabilities.

Ball and Sayre (1974) indicated that concrete thinkers paid a price in that among senior high science students who score A grades, 88.2% were formal, while only 11.2% were concrete. Among the D-F grade students, 81.0% were assessed as concrete operational thinkers, while 19.0% of this group were operating at the formal level. Similar results were reported by Ward and Herron (1980): "Students who are operating at the concrete level of intellectual development suffer a disadvantage when compared to their formal operational classmates, not only on material requiring formal reasoning" (p. 398). Lawson and Renner (1975) warned that science teaching will fail to promote scientific thinking if the concrete thinkers are asked to interact with science on a purely verbal level and their teacher taught them as if they thought formally. They noted that concrete learners could only interact with science on a concrete level and that until they had acquired a sound basis of concrete experiences from which to build, they would not begin to reason hypothetically or in a scientific way. Herron (1975) warned, however, that concrete experiences without guidance were not educationally sound. The student had to be placed in a position which made him or her think about the situation at hand and guided thinking. In the chemistry laboratory, it would be inefficient in terms of time as well as fruitless cognitively to simply provide a student with a set of apparatus (or worse to tell him to assemble his own) and just tell him to investigate a chemistry topic such as buoyancy. What must happen is that the teacher designs an easily understood activity--often using common household apparatus--which when mediated by a carefully designed set of questions will serve as an investigation. In addition to generating cognitive knowledge, the activity should also demonstrate that:

1. The topic in question relates directly to experiences that the student has had (in this case, at the lake or in the bathtub or at the kitchen sink).
2. A pattern existed in his observations from his past experience and that the pattern is illustrated now before him (this is done implicitly; the student is allowed to generate the pattern--he is not told it).
3. The observations from present and past can be used to predict the answers to real life questions: Will the overloaded herring boat make it to port in salt water? Will it arrive safely if it must cross an estuary? Will a car float? How many average people will fit in a row boat?

It is not atypical in Chemistry 11 that one group in a class will find the subject as normally taught by exposition to be terribly easy, while another group, often in the same class, will be overwhelmed and have to resort to memorization of facts just to survive. Abraham (1988) stated that "students sometimes follow the instructions in laboratory manuals without thinking about what they are doing or why they are doing it." Comprehension involves an interactive-constructive process in which a learner associates past experience with the new information presented to invent or construct meaning. If the information presented is so abstract that the person cannot associate it with any prior experience, comprehension will not occur. The level of conceptual abstraction is inherent both in the concept and the representation or presentation of the concept. Many science concepts are so abstract that only a few people can comprehend their meaning, while other abstract concepts can be made more understandable by selecting an appropriate presentation or representation mode.

It is important to note that concrete teaching strategies associated with exemplary teaching will not necessarily translate into better marks on academic achievement tests. While the academic performance problems of concrete operational students enroled in Chemistry 11 may be associated with the observation that courses such as Chemistry 11 are predominantly taught in an expositional manner and as such cater to the formal operational student. It was postulated in this study that the hands on activities which constituted the independent variable would assist in making difficult scientific concepts which often appear to be accessible only to formal operational students, accessible to concrete operational students. However, whether or not traditional academic achievement tests manage to tap any effects created by the hands on activities is altogether another issue.

Cognitive Development

Among students in a grade 11 chemistry class, the teacher typically observes a broad range of abilities in dealing with abstract concepts. Some demonstrate a ready facility with abstractions, others falter sporadically, while some appear incapable of understanding even the simplest abstraction. Cognitive development models suggest that the ability to manipulate abstractions is a fundamental characteristic of formal operational thinking.

The cognitive development theory of J. Piaget has at its centre a hierarchical sequence of stages of thinking. While debate over certain aspects of the theory is ongoing, it is difficult to deny that the stages of thinking theory offers a useful and practical paradigm for education research. According to Piaget, cognitive development proceeds by means of four basic stages: the sensory-motor stage (approximately 0-2 years), the pre-concrete or intuitive stage (approximately 2-7 years), the concrete operational stage (approximately 7-12 years) and the formal operational stage (approximately 12-15 years).

The study group in this research were adolescents whose thinking strategies were typical of concrete operational thought and/or formal operational thought. As a result neither the sensory-motor operational stage nor the pre-concrete stage are discussed.

For the purpose of this study which related to the classroom, it was judged useful to operationalize the stage characteristics. This was done by contrasting typical behavioural characteristics demonstrated by concrete thinkers (students whose thinking strategies were characterized as predominantly concrete operational) with typical behavioural characteristics demonstrated by formal thinkers (students whose thinking strategies were characterized as predominantly formal operational).

The operationalized stage characteristics resulted in a series of descriptions about concrete operational and formal operational students: The formal thinker would not only want to understand a task immediately at hand, he would also wish to understand its implications for future such cases. For the concrete thinker, the task would be one of finding a solution and calling closure. The formal thinker forms hypotheses, makes inferences and gathers evidence to build a structure within which to comprehend the task fully. He looks not only at the task at hand but also beyond it into the realm of the possible. The concrete thinker may well comprehend an immediate problem, but it is unlikely that he will draw inferences beyond the boundaries of the immediate situation. The concrete thinker has difficulty picking up on cue words such as "but" or "consequently" or phrases such as "this is a special case" or "this is not guaranteed to occur." The formal thinkers always have a mental picture of how concepts fit together, but the mental horizon of the concrete thinkers is not as broad; they fail to perceive connections and combinations, and need more lesson structure than their formal counterparts. The formal students are quick to see new combinations and possibilities which seem to elude the concrete students. The formal thinker is far more apt to use more global judgement than the concrete thinker in terms of sorting out what is important in a problem. The concrete thinker is likely to get muddled up in trivial details and often resorts to algorithmic methods of solving problems. Furthermore, algorithmic solutions are often beyond the grasp of concrete students since they often have great difficulty determining which algorithm to use. A typical retort on the part of concrete thinkers who have been told which algorithm to apply is: "Well why didn't you say that in the first place?" Thus the focus is on the solution of the problem, period. While the formal student can pick up meaning by reading between the lines, the concrete student considers information at face value. Hence, the formal reader is facile in adapting to new information since he is capable of equilibrating information by accommodation and assimilation of information while he is experiencing a situation.

The terms equilibrate, accommodate, and assimilate warrant an explanation since they have meanings which are specific to Piagetian theory. While the stages in Piaget's theory are static in the sense that people pass through them, there is also a dynamic aspect which deals with actual information processing.

Accommodation and assimilation function simultaneously while processing new information according to Piaget. Accommodation is the process of adjusting structures to the concept as it is being assimilated and assimilation is incorporation of the concept into accommodated structures. Metaphorically speaking one might rearrange the books in a shelf (accommodation) in order to add a new book (assimilation). When the new concept makes sense in terms of past and present experience, a state of equilibrium called equilibration is said to have been reached.

A number of studies (Howe & Durr, 1982; Naiz & Lawson, 1985; Saunders & Shepardson, 1987; Schneider & Renner, 1980) indicated that the hands on teaching strategies associated with exemplary teaching are, in terms of knowledge, more effective with concrete operational learners and just as effective with formal operational learners as formal traditional instruction.

Formal operational thinkers do not require concrete hands on experience to effectively understand or construct knowledge. This is not true of concrete operational thinkers who require concrete experience on which to build understanding.

Saunders and Shepardson (1987 p. 40) reported various research studies which indicated that the majority of secondary students are concrete thinkers. The studies quoted included:

Researcher	Date	Grade Level(s)	% Concrete
Renner & Stafford	1972	7 - 9	77
Lawson & Renner	1975	7 - 12	75
Wollman & Karplus	1974	7 - 8	85
Fowler & Mulopo	1984	11	50
Staver & Halsted	1984	11 - 12	53

The synthesis by the New Jersey Task Force on Thinking, New Jersey Basic Skills Council (1986) indicated that with regard to teacher observations of student abilities:

> Many students seemed to have particular difficulties with the manipulation of abstract concepts--an essential skill in these [abstract] areas of inquiry. (p. 20)

Students in their study depended on memorization without understanding meanings or connections of concepts to the concrete world. Thus, they could not apply them to new problems even if those problems were only superficially different from those which they could solve by rote. Further, the New Jersey synthesis indicated similar problems with the majority of college freshmen.

It was the author's experience that high school chemistry was taught in a fashion which demanded formal thinking and often neglected the predominantly concrete thinker. Lawson and Renner (1975) agreed with this observation and added that "a major portion of today's secondary school science curricula . . . is beyond the students' level of understanding and, therefore, inappropriate" (p. 347).

Decker and Silverman (1986) found that high numbers of students in secondary schools and in colleges were still primarily concrete operational in their performance and continued that many adults never become formal thinkers. Renner and Stafford (1976) indicated that 75% of the students in secondary schools were primarily concrete operational in their thinking.

The disparity between the misconcept that formal operational thinking is acquired at the age of twelve and the age at which formal operations are actually acquired--if acquired--may be a major factor in poor science achievement among secondary students. Science courses must be modified to take this into proper account. Both science curricula and science instruction should reflect that the majority of secondary school students are concrete operational. These students learn most effectively from inductive concrete inquiry and must be encouraged to develop formal operational abilities. Gable and Sherwood (1980) and Saunders and Shepardson (1987) indicated that secondary science students achieved at a higher level and made easier cognitive gains when exposed to concrete operational versus formal operational instruction. Lawson and Renner (1975) submitted that although formal operational students can reason without the direct need of objects, that in order to develop this type of thought, objects should be used. Further, they found that the level of thought among student groups ranging from elementary to college sophomore could be changed by providing them with learning cycle (exploration, invention, application) inquiry-centred experiences in science. Similar results were found by Lawson (1975), McKinnon and Renner (1971), and Schneider and Renner (1980). Schneider and Renner (1980) reported that: "actual first-hand experience with objects, situations, and/or events builds the mental structures necessary to function with a science concept" (p. 516).

Ward and Herron (1980) listed many studies (Bass & Montague, 1972; Case & Fry, 1973; Goodstein & Howe, 1978; Lawson, Blake, & Nordland, 1975; Nous & Raven, 1973), used to facilitate the acquisition of formal operational logic by concrete operational thinkers. They found that while these studies employed a variety of methods, those which appeared to be successful employed several common factors of which the first of these common factors was direct physical manipulation of objects pertinent to the topic at hand. This physical interaction constitutes the exploration or gathering phase of the learning cycle (Aitkin & Karplus, 1962; Lawson & Renner, 1975b) which consists of three sequential phases: exploration, invention and expansion (application). The second common successful factor was peer interaction. These studies reinforced Piaget's conditions for learning that involve physical experience, social transmission and equilibration. These conditions influence the construction/invention of knowledge structures called schema.

It is critical that teachers use those teaching strategies which best fit the cognitive levels of their students (Yore, 1981; Morine & Morine, 1973). Grade 11 chemistry students must be provided with activities which are concrete in the Piagetian sense; that is, students must be made to interact in direct physical terms with the subject matter at hand in an intellectually supportive interpersonal environment.

Self-Concept

The construct of self-concept is ill defined, inconsistently applied and vague. Hamachek (1985) provided a non-exhaustive list of 20 situation-specific definitions generated between 1890 and 1982 that reflected the apparent turmoil in self-concept research. It is interesting that a construct, so ill defined and vague should hold such value for ministries of education who typically encourage the classroom teacher to enhance self-concept and develop it to its fullest potential. Shavelson, Hubner, and Stanton (1976) agreed that the construct of self-concept had never been clearly defined but that it was important enough to warrant clarification since it was important both as an educational end in itself and as a mediating variable in student academic achievement. It is important to realize however that the variables of academic achievement and cognitive ability are not strongly related to overall self-esteem (Wylie, 1979). A meta analysis of 128 studies conducted by Hansford & Hattie (1982) on the relationship between various self-measures and measures of performance/achievement revealed that "it was not possible to reject the null hypothesis that the true relationship between measures of self and performance/achievement is zero" (p. 127).

The sense in which self-concept was used in this study was that it served as a potential indicator of student enjoyment, and satisfaction with the overall course of study. Since self-concept involves the total organization of ideas about the self, it was not expected that the experimental variable would have significant absolute effect on self-concept since far more events occur in the lives of Chemistry 11 students than occur in the few hours per week spent in class. However, use of the hands on activities in the year prior to the study appeared to generate significant affective gains and as a result, it was considered wise to measure self-concept for two major reasons:

1. to determine whether the apparent past gains in the affective domain were repeatable and measurable and as such might serve to illuminate the classroom anecdotal data;
2. to determine whether the experimental variable had a negative effect on self-concept.

The Self-Perception Profile for Children (Harter, 1985) was used to measure self concept. The literature indicated that teachers could use specific strategies in the classroom in order to improve self-concept. Schilling (1986) suggested, that in order to have a high self-concept, young people must feel capable--that they have skills and are able to achieve. Hamachek (1985) observed that adolescents with healthy self-concept showed characteristics such as: curiosity, perseverance and an engaging attitude toward learning. These characteristics are frequently encouraged as goals of science programs.

Brophy (1979) stated that, contingent upon performance, praise should be used to provide students with self-concept builders such as feelings of: competence, worth, self-appreciation, and effort related to reward. Teachers must have developed learning activities that promoted self-concept of students and praised their students directly when successful assignments were returned to them. Schilling further proposed that in order to enhance high self-concept that students must feel capable--that they have skills and are able to achieve. Secondly, she felt that students needed to feel significant--that what they think, say and do mattered to those around them. Students who described their classroom as more supportive of their autonomy viewed themselves as not only more competent in school but had higher self-esteem than those who saw the classroom as more confining (Grolnick & Ryan, 1987). Schilling (1986) suggested that interactive student-directed activities also fostered positive self-concept. Jones (1986) considered student projects as an important resource to develop classroom cohesiveness. His considerations carried weight, particularly in light of the conclusion drawn by Schilling who observed that less cohesive classroom groups created feelings of anonymity and poor student self-concept. Schilling added that self-concept could be enhanced by selection of topics which reflected group interests, followed by the broadening of those topics to more general concepts. Battle (1981) endorsed the idea that students participate actively in their own education.

Attitude

Shrigley, Koballa and Simpson (1988) stated that "a distinct but complex definition of attitude is evolving. The most distinct attribute is evaluation, our preference to like or dislike something" (p. 675). Attitudes are learned either from direct or indirect experience and can be enhanced by teaching strategies associated with exemplary teaching.

Shymansky (1977/78) suggested that less-directive student centred learning environments made students feel more positive about school. Compatibility between teaching strategy and cognitive demand of course content attempts to avoid the pitfalls associated with teaching concrete operational level learners by using instructional strategies which are better suited to students who operate readily at the formal operational level. Such a mismatch between learners' attributes and instructional demand compounds the conceptual difficulties of an abstract subject like chemistry and adds to student frustration.

Additionally, Lawson (1985) suggested that teachers must challenge students without overwhelming them and that it was very easy to overwhelm some students with abstract subject matter and verbal instruction which served only to frustrate and cause them to dislike a subject. Grossnickle and Thiel (1988) suggested that students preferred that teachers avoid a steady routine of lectures and teacher-dominated activities, integrated course content with student experience and future plans, used teaching skills that included variety and enthusiasm, adjusted to individual learning needs and styles, conveyed commitment to students and created a supportive and facilitating environment. de Charms et al. (1976) demonstrated that teachers could enhance student attitude by setting realistic goals, creating a physically bright and appealing classroom, encouraging student-imposed discipline, moving around in the room to contact students and by taking personal responsibility for the enhancement of student attitude. Green (1977) felt that teachers who positively influenced student attitude demonstrated the characteristics of good communication, credibility, expertise, trustworthiness and were attentive toward the needs of their audience and presented material logically. Drew, Olds and Olds (1974) concluded that students needed to be challenged academically without overwhelming them in order to maximize positive student attitude.

Summary

Teachers used curriculum differently. Some are capable of bringing curriculum to life by using teaching strategies associated with exemplary teaching. While the literature is rich with descriptions of the benefits of teaching by using exemplary methods, this study focused on four specific outcome domains:

1. Knowledge/skill,
2. Cognitive development,
3. Self-concept, and
4. Attitude.

Chapter 3

Treatment

Introduction

Teaching strategies which involve active enjoyable student participation using hands on inquiry centred activities may be perceived as antithical to traditional teaching. Traditionally, student participation meant that the class watched or performed formal lockstep laboratory exercises designed to illustrate that what they had been told in class was, in fact, true. Was the idea that the class would somehow get caught up in the excitement and satisfaction of the scientific endeavour? If this was the intent, these lockstep exercises fell far short of the mark and were perceived by the majority of students as irrelevant, boring, too difficult, too easy or simplistically predictable. A common notion held to this day among science teachers follows the logic that if a student knows how to cook up his results then that student knows his stuff. Perhaps there is some truth to this notion since it is impossible to deny that formal teaching strategies, associated with the traditional classroom, have produced measurable repeatable results and represent a time-honoured tradition among science educators. It is not the intent of this thesis to deny this observation but rather to illustrate that through attention to development of the affective domain as well as the cognitive domain it is possible to produce students who feel better about themselves, their school experience and about subject matter within a formal discipline such as Chemistry, without jeopardizing and with perhaps enhancing cognitive learning. Furthermore positive self-concept, attitudes and thinking abilities are important learning outcomes of any science program.

Research Questions

The specific questions to be answered by this research were:

1. Would differences in student achievement exist between the experimental group and the control group as measured by pre-treatment/post-treatment scores on Chemistry 11 academic achievement tests?

2. Would differences in student cognitive level exist between the experimental group and the control group as measured by pre-treatment/post-treatment scores on the Arlin Test of Formal Reasoning (Arlin 1987)?

3. Would differences in student self-concept exist between the experimental group and the control group as measured by pre-treatment/post-treatment scores on the Self-Perception Profile for Children (Harter, 1984)?

4. Would differences in student attitude toward science exist between the experimental group and the control group

as measured by pre-treatment and post-treatment scores on a British Columbia Ministry of Education Science Attitude Scale (1986)?

5. Would differences in student enjoyment/interest exist between the experimental group and the control group as measured by an assessment of student classroom behaviors (anecdotal record) during the study?

The Setting: Social Context and Sample

The three Chemistry 11 classes under study were part of a western Canadian semi-rural public secondary school (grades 8-12) with an enrolment of 1,150 ± 75 (46% male, 54% female). Local students enroled in the school at the grade 8 level, or enrolment occurred at grade 11 by transfer from one of two junior secondary feeder schools (grades 8 through 10). Thus this single school serviced all the senior students in the district. The school population broken down by grade is provided in Table 1.

Table 1

Population of the School by Grade

Grade	Enrolment
8	110 ±30
9	125 ±20
10	130 ±20
11	420 ±30
12	320 ±30

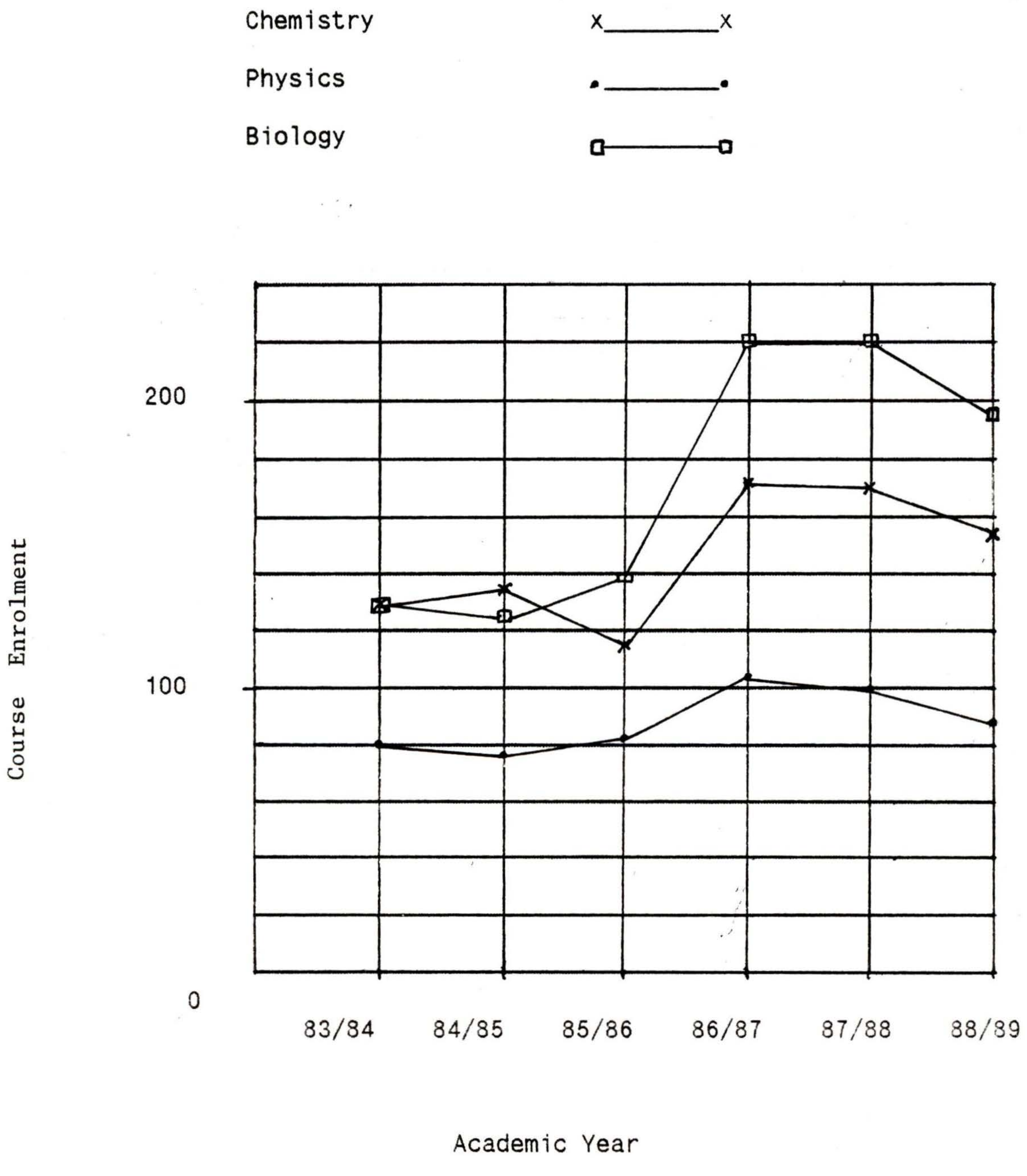
Using as a measure, the number of senior (grade 12) provincial academic scholarships awarded to graduates, the school was regularly one of the top five in the province. It was characterized as a strong traditional academic school. A small proportion of Native students (4%) and English as a Second Language students (1%) attended the school, but no representatives of these groups were enroled in the classes used for this study. All students involved in the study were whites from predominantly middle-class and professional, nuclear families.

The economy of the region was supported by fruit growing and packing, and a very active year-round tourist industry and supporting infrastructure. There was a light manufacturing sector, federal and provincial government regional offices, a federal agriculture research centre, an astrophysical radio observatory, provincial trout hatchery, a growing local two-year college, and a provincial forestry centre. This collection of businesses and service facilities provided employment for the 60 to 70% of all senior (grade 11 and 12) students who held part-time jobs during the school year.

Prior to the 1986/87 academic year, fluctuation in science enrolment (Table 2) was in the order of ± 10%. In 1986, chemistry enrolment jumped by 25% and this new larger enrolment was maintained during the next year, which was the year of the study. This enrolment increase alone was of little consequence to this

Table 2

Science Enrolment 1983-89



study. What was of consequence was the observation that the number of student tutorial sessions increased by some 400% in 1986 and that this new level of demand was generally maintained during the year of the study, 1987. The sudden sustained increase in tutorials necessitated several changes in teaching strategies earlier judged to be appropriate. Ideas for these new strategies were developed during 1986 and 1987.

Initially the study was to use two experimental groups and two control groups. Balancing the teaching assignments, however, left the investigator with only three Chemistry 11 blocks: H and A Blocks with 22 and 25 students respectively were the experimental groups while D Block with 21 students constituted the control group. The number of students who required extra help on a regular basis during the year of the study was: H Block, 6 to 7 students or 25% (one of whom switched to B Block); A Block, 8 to 9 or 35% (one of whom dropped the course); D Block, the control group, 8 to 9, or 39% (three of whom dropped the course). The total instructional time received by each class was equal and was judged to be an insignificant factor in any observed differences. An informal preliminary analysis of student records indicated that the three classes used were nearly equal in general intelligence. No formal analysis was possible because of missing data and the variety of measures used. All students were registered in grade 11; 40% were 15 years of age and the remainder 16 at the start of the academic year of the study. Absenteeism generally was not a problem except for one student from H Block and one from D. Each of these students were regular extra-help recipients. No students were repeating the course.

The Treatment

The Chemistry 11 course as prescribed by the British Columbia Ministry of Education consisted of 8 core topic units involving 90 hours of instruction. Students in this study received a total of 120 instructional hours of which 90 were spent on core material and 30 hours were spent on enrichment. This study involved 14 major activities which spanned 52 one-hour class sessions from November 19, 1987 to March 25, 1988; the 34th to the 85th lesson in the academic year. Table 3 outlines the course as prescribed by the British Columbia Ministry of Education. The curriculum guide reminded teachers that they may wish to rearrange items where appropriate. Consequently, the investigator rearranged the course units as shown in Table 4. Therefore this study dealt with aspects of Mixtures and Separation Techniques, Kinetic theory and the Mole Concept, Formula Writing, Chemical Equations, Heat Temperature and Pressure and Solution Chemistry.

Table 3

The Chemistry 11 Course Outline (1977)

Unit	Title
1	The Scientific Method
2	Description of Matter
3	Classification of Matter
4	A Theory of Matter
5	The Mole Concept
6	Electrical Nature of Matter
7	The Periodic Table
8	Nuclear Chemistry

Table 4

The Chemistry 11 Course As Taught

Course Unit	Instructional Topic	Period	Hours	Period
1	Safety	1	1	Sept. 8/87
	Scientific Method	2-5	4	Sept. 9 - Sept. 17/87
	Scientific Calculations	6-16	11	Sept. 18 - Oct. 9/87
	Density and Buoyancy	17-29	13	Oct. 13/87 - Nov. 5/87
2.	Matter and Heat	30-34	5	Nov. 9 - Nov. 17/87
	Mixtures and Separation Techniques	35-44	10	Nov. 19 - Dec. 11/87
	Kinetic Theory and Mole Concept	45-56	12	Dec. 12/87 - Jan. 15/88
3.	Formula Writing	57-58	2	Jan. 18 - Jan. 20/88
	Chemical Equations	59-70	12	Jan. 22 - Feb. 20/88
4.	Heat, Temperature, and Pressure	71-79	9	Feb. 24 - Mar. 10/88
5.	Solution Chemistry	80-91	12	Mar. 14 - Apr. 13/88
6.	Molecular and Atomic Structure	92-106	15	Apr. 14 - May 13/88
7.	Organic Chemistry	107-120	14	May 16 - June 13/88

Experimental Instructional Treatment

The experimental treatment consisted of involving students in various concrete or hands on activities which constituted the independent variable in this study. The terms instruction, verification and expansion, are typical descriptors for stages in traditional teaching/learning cycles and were used in this study as points of reference. The hands on activities were used to explore a new topic, to verify theory or to expand a concept already treated in class. Where the activity or teaching strategy was used to explore a topic, it was characterized for use in this study as having replaced or having supplemented a formal instruction phase of traditional teaching/learning. Where the hands on activity or teaching strategy replaced a formal laboratory exercise, it was characterized as having replaced a verification lesson or phase so called since traditionally student laboratory work was used simply to verify what the student had been told. Where the activity replaced or supplemented a session designed to expand a topic already covered in class, it was labelled as having replaced an expansion phase of a traditional instruction-verification-expansion teaching/learning cycle. While the goal of this study was to examine possible enhancement of student interest and enjoyment with the Chemistry 11 course, the concrete activities were designed to accomplish this goal in various ways depending on the phase of the traditional teaching/learning cycle replaced:

1. Where the activity replaced the instruction phase its purpose was to provide students with a common set of reference experiences in addition to providing support and structure for observations which they had made in the real world. These instruction activities served the purpose of taking advantage of student prior knowledge in construction of new knowledge and served to link a laboratory exercise with the student's real life.

2. In cases where the concrete activity replaced a verification phase, its purpose was to place students in a situation where they had little choice but to actively participate in a concrete experience which was often their own design and which served to link theory from an instructional phase with a concrete and now personally meaningful classroom experience. The significance of these activities was that students were forced to actively inquire, to decide on and to control their own variables and to review previous work on the topic at hand.

3. In cases where the hands on activity took place in the expansion phase, its purpose was to provide a concrete reality in which to embed theory by involving students in investigations which were at least partly of their own design. These activities were significant since they encouraged students to use hypothetic-deductive inquiry and to control variables as with the verification activities; but they also allowed students to link

the activity into the topic at hand as well as linking it into real life. Science, Technology, Society (STS) educators feel that the latter is an important goal.

Overview of Treatment

The hands on activities were carried out solely by the experimental group. The control group covered the same material but they were taught using a far more traditional pattern: the traditional instruction-verification-expansion teaching/learning cycle. Generally they were told about the topic by lecture (instruction), they carried out formal laboratory exercises designed to verify that what they had been told was true (verification) and they solved problems based on the topic (expansion). While traditional laboratory exercises serve a verification role, the laboratory exercises used by the control group were moved around as necessary to become introductory exercises as well as expansion exercises, or verification exercises. As a result, the control group followed a modified traditional program in terms of sequence but a traditional program in terms of presentation. Each description of the lessons below includes a table which compares the experimental group and the control group in terms of instructional time allocated to an activity, lesson number(s) during which a topic was covered or during which an activity took place (the first lesson of the academic year was not the first lesson of the study which started on November 19, 1987 at lesson 33 and continued to lesson 85, on March 23, 1988) and date(s) of the activity or topic. It is critical to note in terms of experimental design that although instructional times on a single activity may appear to vary between the experimental group treatment and the control group treatment as shown in the table included with the description of each activity that in fact both the experimental group and the control group received the same total instructional time on any topic. It must be remembered that each topic had an instructional, verification and an expansion phase spread out through several lessons and that an activity description does not represent the total time spent on a curriculum topic.

Hands On Activities

Separation, purification and identification of the components of a mixture.

The first activity of the study was a verification activity used following two periods of general instruction on solutions and a demonstration of various separation techniques integrated with a film on mixtures. Both the control and experimental groups received identical instruction up to the concrete activity. The purpose of the activity was to separate and purify a compound (benzoic acid) from a heterogeneous mixture. The mixture consisted of 50% benzoic acid, 20% sodium chloride, 30% sand, enough fairly coarse charcoal to colour the mixture and enough glycerol to give it a mud-like consistency.

Group	Instructional time (min.)	Lesson number(s)	Date(s)
Experimental	110	33, 35, 36	Nov. 19-25/87
Control	90	33, 35, 36	Nov. 19-25/87

The experimental groups were shown the mixture being assembled and were then required to design a method of separation. Their source of information with regard to properties of the components was the teacher who responded in an open session to student questions. Students were not allowed access to the laboratory area until they had worked out a separation technique. Student questions were guided by the teacher to raise various solubility issues.

The control group experienced a formal laboratory exercise. They were informed about what was in the mixture and were referred to where the laboratory handout sheet listed relevant properties of the components. The laboratory exercise sheet was explicit on the exact properties of the mixture components which would facilitate their separation and the students simply followed the instructions to verify that what they had been told was in fact true.

For the experimental groups, the second period of the activity started with a group-initiated discussion on problems encountered in the first session. Crystal sizes were compared among laboratory groups and the variance created a need to know how to maximize crystal size. Students then regrew their crystals and the last part of the session was used to discuss methods of determining crystal purity.

The control group had been explicitly told on the first day how to solve technique problems and on the second day they continued with their exercise as per the laboratory instruction sheets. The last fifteen minutes of this period were used to tell the students of the control group about how they would test crystal purity.

The first portion of the third period was used by the experimental groups to work out with the instructor a specific method of testing the purity of the benzoic acid. The test for purity was then carried out. The control group tested purity according to explicit instructions in the laboratory handout sheet.

Paper chromatography. This activity replaced a traditional instruction/ verification phase. The purpose was to separate the component solutes in a homogeneous (liquid/liquid phase) solution. Neither group had received formal instruction on paper chromatography although a film on various separation methods (including chromatographic techniques) had been shown to all classes several periods before this activity started.

Group	Instructional time (min.)	Lesson number(s)	Date(s)
Experimental	80	37, 38	Nov. 24-30/87
Control	70	37, 38	Nov. 24-30/87

The experimental groups were required to bring their own samples to class--ones which they considered to be appropriate for paper chromatography. At the start of the hands on session, the students and teacher decided which of the sample were to be used. Students were shown a variety of solvents (with safety warnings clearly marked), shown a typical separation apparatus, and were instructed to carry out their separations. Since students worked on a variety of samples, student data was tabulated on the blackboard. Design of the blackboard table involved the instructor and four students who were working near the blackboard.

The control group followed a highly structured laboratory exercise where all instructions were explicit and where the students were provided with solutions to separate. Data were placed directly in student workbooks and was analyzed during the first twenty minutes of the following session.

Heating curves. This activity replaced an instruction phase and hence was characterized as an information-gathering experience which took one class period. The purpose of the activity was to collect data about the temperature changes occurring in a sample of crushed ice as it was heated to boiling.

Group	Instructional time (min.)	Lesson number(s)	Date(s)
Experimental	60	40	Dec. 1-2/87
Control	60	40	Dec. 1-2/87

The experimental groups were simply instructed to heat the ice to boiling and show their results in the best way possible. Class data were used at the end of the session to develop a graph which best represented the data collected. The control group was given explicit instructions on the laboratory blackboard as to how to set up the apparatus, exactly what to do, and how to set up both a data table and a graph to represent their data.

Solid/solid solutions. This was a thirty-minute activity which served as an instruction/verification phase. The purpose was to assist students in recognizing the properties of, and becoming familiar with solid in solid solutions. The experimental groups were told two to three days prior to the session to collect solid in solid samples to bring to class. Students were given no instruction as to the nature of this type of solution. During the activity, students presented their samples, which were passed freely around, and were asked to defend their reasons for choosing their sample. Properties and sample names were placed on the blackboard to be recorded by all students in the experimental groups. The control group was lectured on the properties of solid/solid solutions, took notes, and was shown samples without having to handle them.

Group	Instructional time (min.)	Lesson number(s)	Date(s)
Experimental	30	42	Dec. 3-6/87
Control	30	42	Dec. 3-6/87

Separation techniques. This activity supplemented an expansion phase of a traditional teaching/learning cycle. Both the experimental group and the control group had received instruction on separation techniques as the course progressed and had had prior practice with separation techniques. The activity was designed to provide a concrete experience concerning the differences and similarities between various separation techniques. The experimental group classes were divided up into teams of 4 or 5 students. Each team was assigned a separation technique--electrolysis, chromatography, distillation, filtration or centrifuge separation--to demonstrate to the rest of the class by simulation and role playing using spring and ball molecular models. After each team had completed its presentation, other teams were allowed to constructively criticize. Similarities and differences between the various techniques were compiled on a blackboard. The control group read about and made notes individually on separation techniques, their similarities and differences.

Group	Instructional time (min.)	Lesson number(s)	Date(s)
Experimental	45	44	Dec. 6-7/87
Control	45	44	Dec. 6-7/87

Gases, gas volumes and particles. This activity called on a variety of principles of atomic and molecular structure used earlier in the course. In the sense that the ultimate teaching objective was new to the classes, this activity was judged to replace the instruction phase of traditional science teaching. The objective of the session was to demonstrate Avogadros hypothesis that equal volumes of gases measured under conditions of equal temperature and pressure will contain the same quantity of particles.

Group	Instructional time (min.)	Lesson number(s)	Date(s)
Experimental	60	46	Dec. 14-15/87
Control	60	46	Dec. 14-15/87

The experimental groups worked in pairs in the laboratory using spring and ball molecular models. The entire session was controlled directly by the instructor; no instruction sheets were used. Students were told that they were to build models and would be using the laboratory floor to distribute their models. Various colours of balls were selected by consensus to represent the elements hydrogen (red), carbon (black), nitrogen (green), and chlorine (yellow). Student pairs were asked to construct a model of either atomic or elemental hydrogen. Models were held up for display and quiet comparison and the request was repeated for elemental or atomic chlorine. Student input was requested to illustrate the difference between atomic samples and molecules of diatomic gases. Students were then instructed to try constructing a molecule of methane or marsh gas. Various models came forth and consensus was reached when the class was reminded of the empirical formula--CH_4. The entire group of students were then asked to build a total of about 100 hydrogen molecules among them and to space them evenly on the floor. Students were told that the room was now to be considered as a rigid container in which a gas sample had been placed and that the floor represented one level in the container. The class was questioned as to how they might raise the pressure of the gas. The suggestion of adding more gas or more of another gas was demonstrated and it was shown that the gas particles would have to be closer together. The idea of speeding up the particles was discussed and students were asked to think of a non-destructive way to show this in concrete terms. The hydrogen on the floor was substituted with about 100 models of the methane molecule, equally spaced. It was proposed that equal spacing meant equal pressure.

It was suggested to the class that equal volumes of gases contain equal particles since the particles (volumes) are so small compared to the spaces around them as shown on the floor by the small hydrogen molecules and the relatively large methane molecules. It was explained to the classes that on scale only one or two molecular models would fit on a football field, so both large and small gas molecules acted like tiny points in a vacuum. Further discussion tied in the notion of pressure as a function of the number of molecular collisions per unit time, but left unanswered the suggestion that equivalent volumes of various gases may have different pressures due to differing molecular weights of particles.

The control group treatment followed the same lesson plan as with the experimental groups, except that the students did not manipulate any models. The teacher showed the models and explained the concepts at the front of the laboratory. Students were unable to view the models on the floor since time restraints prevented the instructor from showing this. Rather, he held up a pair of hydrogen models and then a pair of methane models and explained the concept at hand. Students took notes as the teacher demonstrated.

The speed of gas particles. This activity replaced an instruction phase. Its purpose was to make direct observations of the relative speeds or diffusion rates of gas particles in air. Hydrogen chloride and ammonia were introduced simultaneously at opposite ends of a clean glass tube. The position within the tube where the gases met was observed by the formation of a white reaction front composed of ammonium chloride particles.

Group	Instructional time (min.)	Lesson number(s)	Date(s)
Experimental	30	47	Dec. 15-17/87
Control	30	47	Dec. 15-17/87

The experimental treatment consisted of having the students build spring and ball models of an ammonia molecule and a hydrogen chloride molecule. They were shown the apparatus and the procedure was described. They were then reminded that the issue of molecular rates of travel was left unanswered in the exercise which led to the derivation of Avogadros hypothesis. They were challenged to predict where the reaction front would appear and to describe why, using any classroom textbooks for reference. Ten minutes was allowed for a search in their textbooks and the classroom library. The student groups then submitted their answers, worth a possible 5 marks, to the teacher and the demonstration began. While the class waited for the results, the teacher read off the predictions and separated them into piles according to a right-side or left-side prediction. The prediction was worth one mark out of five and the reasoning was worth four. When the reaction was complete, the class and the teacher presented the reasons given by the winning side explanations, then by the losing side explanations and settled on a reasonable explanation for the position of the reaction front based on the kinetic molecular theory. The control group treatment consisted of showing the demonstration and then explaining it in terms of the kinetic molecular theory.

Reaction types. This activity replaced an instruction phase in a traditional teaching/learning sequence. The purpose was to help students understand the nature and the types of common (electron) chemical reactions.

Group	Instructional time (min.)	Lesson number(s)	Date(s)
Experimental	50	26	Jan. 21-22/87
Control	40	26	Jan. 21-22/87

The experimental groups used spring and ball models to construct models of about ten molecules which were reasonable in the sense that they could be named. They were asked to name them by placing each on a piece of paper with the name and formula. Groups switched places to observe and critique the work of other groups. Problems were pointed out and with the teacher in attendance corrections were made. Groups moved back to their stations and were asked to show any chemical reaction of their choice and run it through with their laboratory partner. They were asked to write the reaction on a notebook page and instructed to assemble and record on paper three other reactions which had to differ significantly from the first one they had done. The laboratory blackboard was then used by the instructor to illustrate four common reaction types: addition, decomposition, single replacement, and double replacement in the format:

1. $A + B \rightarrow AB$ Addition
2. $AB \rightarrow A + B$ Decomposition
3. $A + BC \rightarrow AC + B$ Single Replacement
4. $AB + CD \rightarrow AC + BD$ Double Replacement

Groups were asked who had constructed a reaction type which mimicked the $A + B$ — AB sequence. Any group who missed this, set one up while groups checked their reactions against the four types on the board. This procedure was repeated until all groups had accomplished the four types. Students and teacher then considered reactions which did not fit exactly into the four categories. The control group received formal lecture instruction on reaction types and used a worksheet of standard balanced chemical reactions to learn how to identify the four basic reaction types.

Reaction demonstration. The purpose of this activity which replaced an instruction phase was to link together three facets of high school chemistry: the description of a chemical reaction, the balancing of the written reaction, and the observed reality of the reaction itself. The experimental treatment consisted of presenting the class with a worksheet on chemical equations (Figure 1).

Group	Instructional time (min.)	Lesson number(s)	Date(s)
Experimental	40	27	Jan. 25, 26/88
Control	20	27	Jan. 25, 26/88

The reactions to be studied were descriptively written in a three-step format. Experimental group students were asked to read the long-hand version of the sodium/water reaction then make models of the reactants and the products. They then wrote the respective formula in line (1). The students then rearranged the model reactants to produce the model products. Students were shown the first reaction in a small, well-ventilated petri dish. The process was repeated for the second reaction, but was carried out in a 500 mL graduated cylinder where sparks were produced as per reaction 2. Students then solved reaction 3 and balanced the double reactions on lines (5) and (6). The instructor then demonstrated a carefully controlled hydrogen/air explosion. The

Worksheet on Chemical Equations

1. Dry metallic sodium is placed in a test tube with water. A vigorous surface reaction occurs, which gives off sparks and produces a potentially explosive hydrogen gas. In addition, sodium hydroxide is produced, which goes into solution with the water.

(1) 1. Basic ingredients →
(2) 2. Balanced format →

Reactants Products

2. The hydrogen gas is ignited by the sparks. An explosion immediately ensues, atmospheric oxygen is consumed and water is produced.

(3) 1. Basic ingredients →
(4) 2. Balanced format →

Reactants Products

3. Dry metallic sodium is placed in a test tube with water. A vigorous surface reaction occurs, which gives off sparks and produces a potentially explosive hydrogen gas. In addition, sodium hydroxide is produced, which goes into solution with the water.

The hydrogen gas is ignited by the sparks. An explosion immediately ensues, atmospheric oxygen is consumed and water is produced.

Write the balanced, two-step reaction sequence.

(5) I.
(6) II.

Figure 1. Worksheet on Chemical Equations

remainder of the time was used to balance lines (5) and (6) as a single reaction, which was mimicked by models. The control group completed this entire activity without viewing any reactions. This group took 20 minutes for the activity, which left time to go on to another problem set in the same class period.

Measurement scales. This was a homework activity assigned solely to the experimental groups and was designed to supplement an instruction phase in the traditional teaching/learning cycle. The purpose of the activity was to provide students with a common background experience from which to draw in a classroom session where Fahrenheit, Celsius and Kelvin temperature scales were derived and explored. The concrete nature of the homework assignment (Figure 2) derived from a common experience of the students in the study--driving an automobile.

Group	Instructional time (min.)	Lesson number(s)	Date(s)
Experimental	20	72 (Homework)	Feb. 25-29/88
Control	20	72	Feb. 25-29/88

The experimental group treatment included a review of the answers from the homework assignment as well as a discussion of the meanings of the answers as they applied to the Fahrenheit, Celsius an Kelvin temperature scales. The control group received

Homework Assignment

Assume you are in a car which is moving, but at a certain low speed you hear a clicking noise. You don't often go that slowly, except once in a while. Also, when the car goes fast enough, there is a speed at which the car won't go faster until you activate the streamlining panels. Below is a speed scale. Label it somehow, using the above information.

SPEED SCALE ____

Questions

1. Is there a zero?
2. Did you place divisions on the scale?
3. Why?/Why not?
4. Are your divisions correct?
5. What are your divisions based on? (if you used them)
6. Could you do other divisions based on something else?
7. Is your scale ABSOLUTE or RELATIVE?
8. What does ABSOLUTE mean?
9. Could this scale be likened to a temperature scale?
10. Draw a temperature scale; is it ABSOLUTE?
11. Could you make an ABSOLUTE scale?
12. Now draw it.

Figure 2. Homework assignment.

a formal lecture on the three temperature scales. The lecture did include the speedometer notion, but students were not exposed to the homework sheet (Figure 2).

Understanding a definition. This activity substituted for a traditional instruction phase. The purpose was to understand a complex but standard definition of temperature:

> . . . the condition of a body that determines the transfer of heat to or from other bodies and is a manifestation of the average translational kinetic energy of the molecules of a substance due to heat agitation.

Group	Instructional time (min.)	Lesson number(s)	Date(s)
Experimental	45	73	Feb. 29-Mar. 1/88
Control	35	73	Feb. 29-Mar. 1/88

All classes began this activity in the same fashion. They were asked to observe a series of diagrams on the blackboard (Figure 3).

The experimental group treatment began by asking students to make some interpretations of the diagrams. This activity was guided by the teacher and created a need to know exactly what the terms temperature and heat meant. A formal definition of temperature was presented to the class, which was

Heat Diagrams

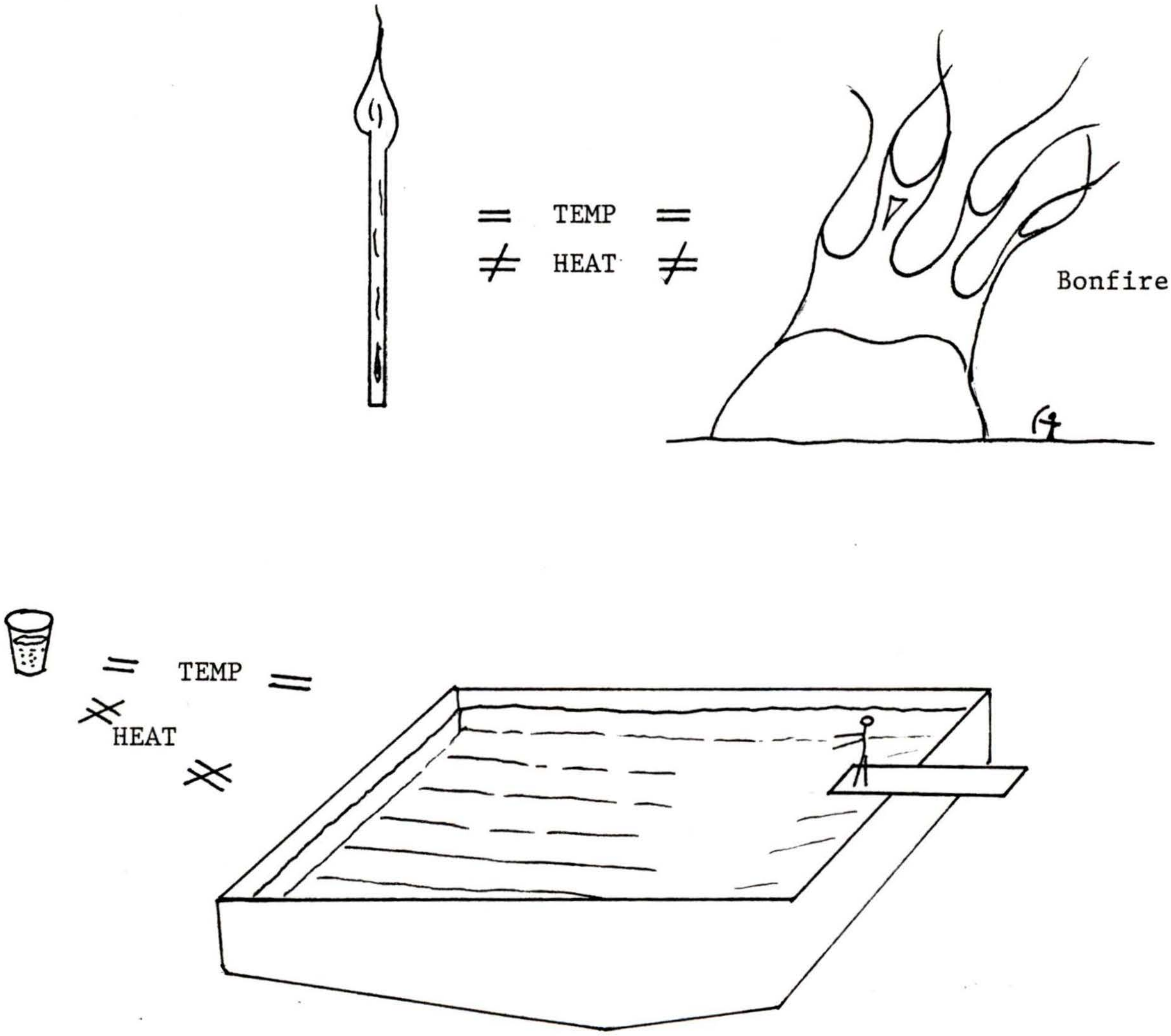

= TEMP =
≠ HEAT ≠
Bonfire
= TEMP =
HEAT
≠ ≠

Figure 3. Heat diagrams.

asked to read it through. Responses were sought and were openly discussed. These comments led to a situation where the definition needed to be separated and analyzed. The class was divided into teams and given five to ten minutes to analyze one of the underlined sections of the definition in order to explain that section to the rest of the class in clear unscientific language. When the class reconvened, each group in turn presented its analysis and notes were added in and around the definition on the blackboard. The formal definition was written out by the students, who added amendments or notes as they saw fit. A formal definition of heat was given as the sum of the translational kinetic energy in a body and students were asked for homework to rewrite the definition in their own terms. The lesson was closed with a general discussion on scientific definitions which was designed to convey various notions about scientific definitions:

1. Definitions are manufactured by people for use by other people.
2. The definition often reflects the language of the day.
3. The definition means little or nothing if it lacks any applied meaning--that is, if it cannot be used.
4. Definitions go through a process of polishing prior to acceptance or publication.

The control group lesson started with an analysis of the board diagrams (Figure 3), but this analysis was teacher generated and involved the class only as far as answering questions was concerned. Certain practical differences between the notions of temperature and heat were discussed which led to presentation of the definitions with the underlined sections. The class was told that the underlined sections often gave students some difficulty. The teacher then explained the meanings of the underlined sections. Students copied down the board notes and definitions. The control group was then instructed on the same four general notions about definitions that had been presented to the experimental groups. This instruction involved the class to a limited extent in a traditional question/answer session. Students used the remainder of the instructional period to look up and record the meanings of the heat transfer terms, conduction, convection, and radiation.

Heat of vaporization of steam. This hands on activity replaced a verification phase of the traditional teaching/learning cycle. Its purpose was to have students measure the heat of vaporization (ΔH_v) of steam in Joules/gram. Both groups had completed a laboratory exercise four periods prior to this lesson in which they had determined the heat of combustion (ΔH_c) for candle wax.

Group	Instructional time (min.)	Lesson number(s)	Date(s)
Experimental	90	70	Mar. 9/88
Control	60	70	Mar. 9/88

The experimental groups were asked to use ten minutes of class time to design a procedure for the ΔH_v determination and to decide themselves on an appropriate apparatus. Class input then enabled the teacher along with the students to develop a calculation/flow chart (Figure 4) on the blackboard. This chart addressed procedural difficulties which had become apparent to the students in their ten minute design session and served as a guide for the laboratory exercise.

The experimental groups were then provided with a formal laboratory handout sheet and instructed to use this in conjunction with the blackboard diagram as they carried out the investigation. The formal handout is reproduced in Table 5.

The control group was instructed that they were to carry out a laboratory exercise to determine the heat of vaporization of steam. The pertinent calculations were reviewed ($Q = mc\Delta t$ and $H_c = Q/\Delta m$), along with safety precautions. A sample was demonstrated for the group which was then provided with the same formal outline (Table 5) provided the experimental group students. The control group followed the handout instructions with no assistance from the blackboard guide diagram (Figure 4).

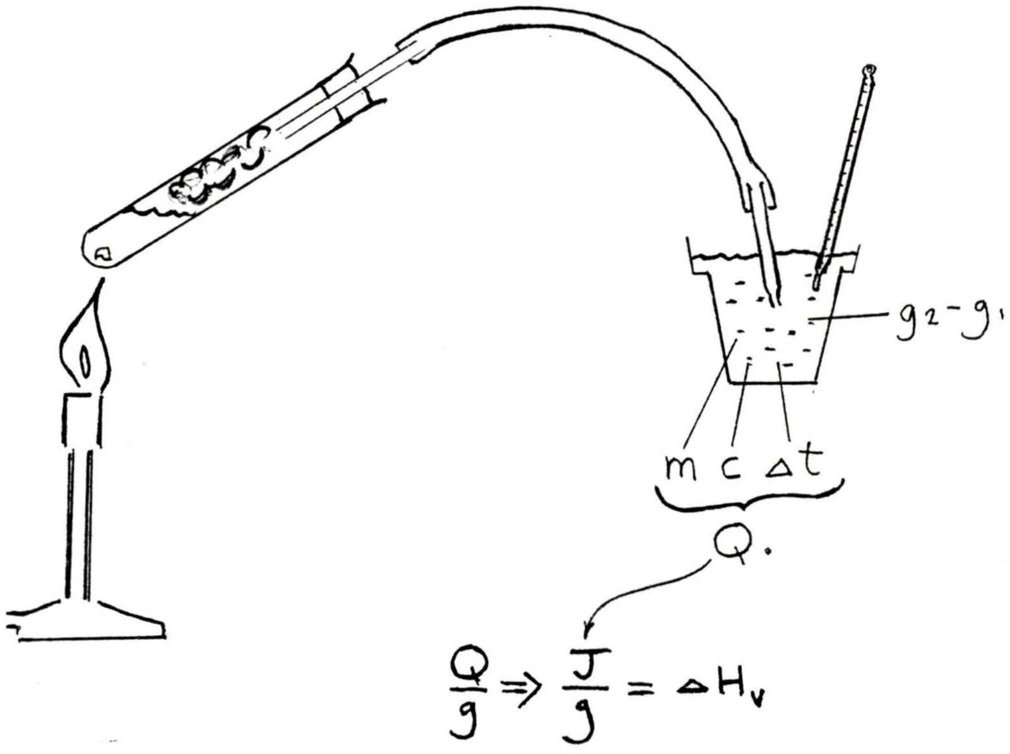

g₂-g₁
m c Δt
Q.
Q/g ⇒ J/g = ΔHv

Figure 4. Calculation/flow chart ΔH_v steam.

Table 5

Laboratory Outline for the ΔHv Determination

Procedure:

1. Weigh the styrofoam cup (calorimeter)
2. Pour 100 mL of tap water into the cup and reweigh it.
3. Add about 25 mL of water along with a few boiling chips to a large test tube.
4. Connect the rubber tubing to the test tube.
5. Heat the water in the test tube until steam is coming out of the end of the tubing at a brisk but steady rate.
6. Record the water temperature in the calorimeter.
7. Shake condensed water out of the rubber tubing.
8. Put the end of the tubing into the calorimeter water so that the water vapour condenses below the surface of the cool water.
9. Keep the water in the test tube boiling evenly and stir the water in the calorimeter with the thermometer.
10. When the water in the calorimeter has risen 20° C, remove the rubber tubing from the calorimeter water, then stop heating the test tube.
11. Stir the water in the calorimeter and record the temperature ± .2°C.
12. Reweigh the calorimeter and contents in order to determine the weight of the liquid condensed.

Data

1. Weight of the calorimeter + water + cup =
2. Weight of cup =
3. Weight of calorimeter + water =
4. Weight of water + cup + condensed liquid =
5. Weight of water + cup =
6. Weight of condensed liquid =
7. Change in temperature of calorimeter water (Δt) =

Titration calculations. The purpose of this activity which replaced part of an instruction phase was to have students make a mental connection between the balancing coefficients in a written (Arrhenius) acid base neutralization reaction and the numbers of H^+ and OH^- particles actually involved in the neutralization.

Group	Instructional time (min.)	Lesson number(s)	Date(s)
Experimental	40	81	Mar. 16, 17/88
Control	25	81	Mar. 16, 17/88

The experimental groups used ball and spring models to mimic reactions which they had balanced as part of a work sheet. The unbalanced reactions were written on the board:

1. $HCl + NaOH \rightarrow HOH + NaCl$
2. $HNO_3 + Ca(OH)_2 \rightarrow HOH + Ca(NO_3)_2$
3. $H_3PO_4 + KOH \rightarrow HOH + K_3PO_4$

Students were required to build models of the reactants HCl and NaOH using red balls to represent hydrogen and black to represent oxygen. They then dismantled the appropriate segments as shown below:

$$H^+ / Cl^- + Na^+ / OH^-$$

and then assembled the segments to produce the products, HOH and NaCl. This process was repeated for the other two reactions where two students had to manufacture enough acid or base molecules to balance respectively the OH^- particles or the H^+ particles.

The control group did not experience this activity but rather received a traditional expository lesson on equation balancing, which consisted of showing students how to balance by lecturing to them and using blackboard demonstration.

Salts--precipitation reactions. The purpose of this activity which constituted part of an instruction phase was to help students appreciate the sequence of events involved in aqueous precipitation reactions, and to understand the terms precipitation, spectation, hydration, soluble and insoluble. Each group was exposed to a similar lecture which followed a series of diagrams developed on the blackboard. Students in both groups were initially provided with a handout sheet which illustrated the lesson outline and included an outline of the process shown in complete form in Figure 5. The student version initially lacked titles of any kind and particle charges. The difference in treatments rested in the fact that the experimental groups were required to build spring and ball models to represent each phase of the reaction, whereas the control group followed a lecture and took notes.

Group	Instructional time (min.)	Lesson number(s)	Date(s)
Experimental	85	85	Mar. 22, 23/88
Control	85	85	Mar. 22, 23/88

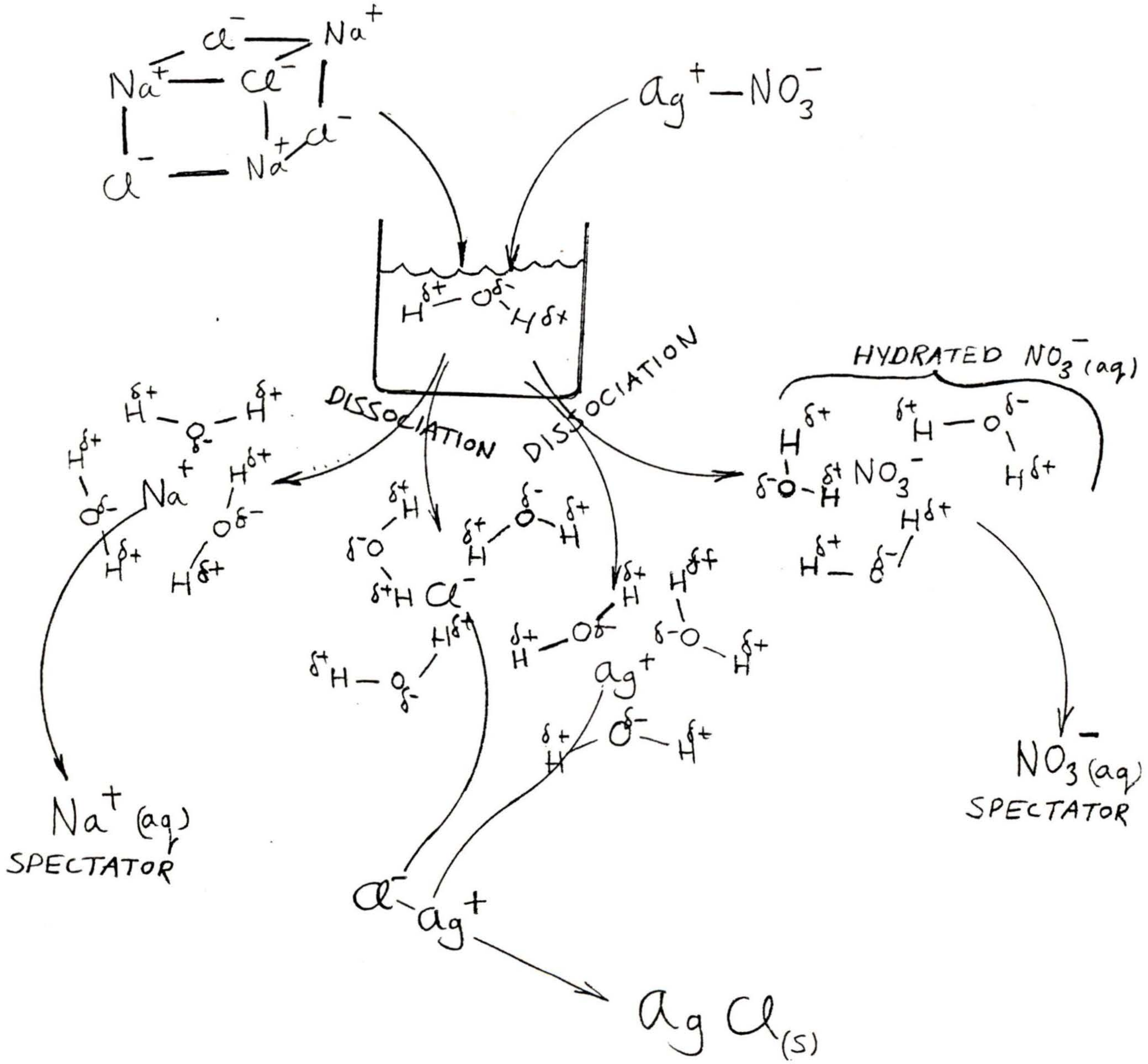

Na+ Cl− Na+ Cl− Na+ Cl− Cl− Na+
Ag+—NO3−
Hδ+—Oδ−—Hδ+
DISSOCIATION
DISSOCIATION
HYDRATED NO3− (aq)
Na+ (aq)
SPECTATOR
NO3− (aq)
SPECTATOR
Cl− Ag+
AgCl(s)

Figure 5. Completed blackboard review of a precipitation reaction.

Measures of Student Attributes

This study explored the effects two instructional treatments had on two comparable groups of students in Chemistry 11. The central foci of the research questions were science achievement, cognitive development, attitude toward science and self-concept. These data were collected on both the experimental and control groups on pre-treatment/post-treatment schedule.

Science Achievement

Since the first school term ended eight school days prior to the start of the study and since term 1 results were comprised of marks from two laboratory activities and two major tests, the first term final mark was judged to represent a reasonable measure of pre-treatment achievement for comparison purposes in Chemistry 11, and thus constituted the pre-treatment student marks sample. The post-treatment student achievement marks sample was comprised of marks generated between the close of the study and the end of the school year. This sample constituted 3 tests and 1 laboratory activity. Each of the 4 assessments was administered after the in-class research for this study was completed. One of the tests was the last given in term 3, while the other 3 assessments constituted all marks from topics taught solely in term 4.

Cognitive Development

The Arlin Test of Formal Reasoning (Arlin, 1987) designed as an application of Piaget's developmental theory to assess logico-mathematical abilities of students at one of five levels: concrete, high concrete, transitional, low formal, and high formal, was administered 4 periods after the start of the study in order to provide pre-treatment cognitive level data. Post-treatment data on cognitive level was provided by students re-writing the Arlin test of Formal Reasoning 4 periods after the end of the study; this being the earliest convenient date on which all students could write the post-treatment instrument. According to Arlin (1987):

> The items selected for the ATFR closely parallel the description of tasks employed by Inhelder and Piaget (1958) to clinically assess an individual's ability to use the eight specific concepts associated with the stage of formal operations. These eight concepts are called the eight formal operational schemata. They are defined by Inhelder and Piaget as: . . . the concepts which the subject potentially can organize from the beginning of the formal level when faced with certain kinds of data, but which are not manifest outside these conditions . . . . (p. 13)

The ATFR (grades 6-12) consisted of 32 items which represent exercises in logical thinking. Each item was assigned to one of the eight clusters associated with formal operations: (1) Multiplicative compensation, (2) Probability, (3) Correlations, (4) Combinatorial reasoning, (5) Proportional reasoning, (6) Forms of conservation beyond direct verification, (7) Mechanical equilibrium, and (8) The coordination of two or more systems or frames of reference. All items were presented in multiple choice format with a sentence stem, diagram and forced responses. Overall readability (using Chall's formula) was at the grades 5 to 7 level. Estimates of reliability for the total test used the Hoyt method and ranged from .71 to .89. The Cronbach Alpha estimates for internal consistency for the total test ranged from .60 to .73 and test retest reliability ranged between .76 and .89.

Self-Concept

The Self-Perception Profile for Children (Harter, 1985) was administered seven days after the start of the study, this being the earliest convenient time in terms of class scheduling after the Arlin Test of Formal Reasoning (Arlin, 1984) was administered. A major exam fell after this latter test and review of answers followed immediately. The post-treatment measure of self-concept was taken using the Harter Self-Perception Profile for Children (Harter, 1985) on April 28-29, 1987, five days after the conclusion of the study; once again this was somewhat delayed due to scheduling problems. The Self-Perception Profile for Children (Harter, 1985) was designed to assess students' domain-specific judgements of their competence as well as global perception of their worth or self-esteem as a person. Specifically the domains were:

(a) Scholastic Competence,
(b) Social Acceptance,
(c) Athletic Competence,
(d) Physical Appearance,
(e) Behavioural Conduct, and
(f) Global Self-Worth.

The initial target population of this scale was third through sixth grade children, but Harter suggested it could be used for older students (p. 21). The additional subdimensions or domains on the adolescent version of the scale--romantic appeal, close friendship and job competence were judged as not playing a significant role in this study.

Internal consistency reliabilities for all six subscales on the instrument used were judged acceptable based on Cronbach's Alpha between .71 and .86 (pp. 12-14).

Attitude

A Likert Scale developed by the British Columbia Ministry of Education Student Assessment Branch for the 1986 British Columbia Science Assessment Program was used to monitor interest and motivation. Specifically, the scale used was:

> School Science, which was designed to assess students' general attitudes toward science as a school subject. Psychometric data for the scale (1982, British Columbia Science Assessment General Report, p. 31) indicated the School Science scale's reliability to be .80.

The School Science Scale was administered as a pre-treatment measure 9 days after the inception of the study and as a post-treatment measure 3 days after the end of the study.

Personal Perspective Regarding Joy of Learning

Anecdotal records and four student notebooks from both the control group and the experimental group sessions were kept. In addition to reporting student comments and teacher feelings, there were included comments from the principal who was evaluating the investigator during part of the study. Data were categorized for each session into positive, neutral, and negative comments and compared between the experimental group and the control group. Teacher feelings, student comments and principal comments were reported in this study.

Data Collection

The objective pre-treatment and post-treatment instruments were administered to each group according to the following schedule:

Instrument	Pre-	Post-
Arlin Test of Formal Reasoning	Nov. 30, 31/87	Apr. 22, 25, 26/88
Harter Self-Perception Scale	Dec. 6, 7/87	May 12, 13/88
Attitude Toward Science Scale	Dec. 8, 10/87	Apr. 28, 29/88

Data Analysis

The Arlin Test of Formal Reasoning (Arlin, 1984), which measured student cognitive development; the Self-Perception Profile for Children (Harter, 1985), which assessed student self-perception; student academic achievement scores and the Student Attitude Toward Science Scale (British Columbia Ministry of Education, 1986) were each analyzed by comparison of pre-test/post-test scores followed by a *t* test for independent samples to determine if any observed differences were significant. Anecdotal records and student comments were analyzed for significant differences.

Chapter 4

Results and Discussion

Introduction

Instructional treatment represented the independent variable in this two group pretest-posttest design study. Students in both the experimental and control groups received 52 hours of formal instruction and were required to meet identical performance criteria in terms of traditional written chemistry examinations. The purpose of the study was to explore the effects on students of teaching Chemistry 11 using a variety of non-traditional teaching strategies as compared to the effects on students of traditional teaching strategies. In order to operationalize this design, it was necessary to ensure student anonymity. This condition necessitated the use of group data only, and consequent analysis using a series of two-group *t* tests on pre-treatment/post-treatment data.

Research questions considered related to:

1. student cognitive ability,
2. student cognitive level,
3. student self-concept,
4. student attitude toward science, and
5. student enjoyment/interest.

Respectively, each research question was examined using:

1. student academic achievement scores (marks);
2. the Arlin Test of Formal Reasoning (Arlin, 1984);
3. the Self-Perception Profile for Children (Harter, 1984); and
4. a British Columbia Ministry of Education Student·Attitude Toward Science scale (B.C. Ministry of Education, 1986); and
5. anecdotal records.

Analysis of Quantitative Data

Group comparisons were performed using two-group $\underline{t}$ test for independent groups at the 0.05 level of significance. Comparisons were made between:

1. pretreatment scores for the experimental group and the control group as a means of determining whether the study involved statistically equivalent groups,

2. posttreatment scores for the experimental group and the control group as a means of determining equivalence after the study,

3. pretreatment-posttreatment gain scores for the experimental group as a means of measuring change over the course of the study, and

4. pretreatment-posttreatment gain scores for the control group as a means of measuring change over the course of the study. This four-stage analysis was carried out as necessary on results from each of the four quantitative measuring instruments. Analysis of scores from academic achievement tests, reported in Table 6, indicated that the groups were comparable as measured at pretreatment ($t = 1.76$, $df = 72$, $p \gtrsim 0.05$) and as measured at posttreatment ($t = 1.41$, $df = 38$, $p \gtrsim 0.05$). It was concluded from the chemistry achievement scores, that within the statistical limits of this study that the experimental group and the control group were equivalent. Since chemistry content changed through the academic year and, therefore, different academic achievement tests were used, any analysis of gain for the experimental group compared to gain for the control group was judged as an invalid indicator and was not considered (Table 6).

Analysis of scores from the Arlin Test of Formal Reasoning (Arlin, 1984) revealed that the experimental group was equivalent to the control group on pretreatment data ($t = 0.73$, $df = 61$, $p \gtrsim 0.05$) and on posttreatment data ($t = 0.91$, $df = 57$, $p \gtrsim 0.05$). Analysis of pretreatment/posttreatment data

Table 6

Means, Standard Deviations and Numbers for Student Academic Achievement Scores (%)

Group	Pretreatment	Posttreatment
Experimental	$\bar{X}$ 69.14 SD 14.61 n = 50	$\bar{X}$ 62.11 SD 16.50 n = 46
Control	$\bar{X}$ 62.75 SD 14.77 n = 24	$\bar{X}$ 58.75 SD 13.96 n = 21

Table 7

Means, Standard Deviations and Numbers for Arlin Test of Formal Reasoning Scores (Arlin, 1986)

Group	Pretreatment	Posttreatment
Experimental	$\bar{X}$ 20.05 SD 5.08 n = 43	$\bar{X}$ 22.08 SD 4.10 n = 39
Control	$\bar{X}$ 19.0 SD 5.68 n = 20	$\bar{X}$ 21.10 SD 3.46 n = 20

revealed statistically significant change in the experimental group scores which was not immediately obvious by simple numerical comparison of group means from the pretreatment to posttreatment values. The means for both the experimental group and the control group increased by approximately 2 points. However this may not have signified equivalent gain, since a 2 point mean gain where n = 20 may happen purely by chance, given the range and standard deviation of scores, whereas the 2 point mean gain where n = 43 yielded a statistically significant result, given the nature of the t test. This statistically significant change was not revealed by a posttreatment comparison between the experimental group mean gain and the control group mean gain since the t-test results are necessarily more conservative when group sizes differ considerably. This conservatism usually creates no problem since it is intuitively better to err statistically on the side of conservatism, but consequently in this case, analysis of pretreatment/posttreatment data revealed a result which was beyond the capacity of the more conservative application of the t test. Analysis of pretreatment/posttreatment scores generated by the Arlin Test of Formal Reasoning (Arlin, 1984) indicated that the experimental group gain was substantially significant at the p 0.05 level (t = 1.98, df = 80) whereas gain in the control group score was not statistically significant at the 0.05 level (t = 1.41, df = 38) (Table 7).

Table 8

Means, Standard Deviations and Numbers for the Self-Perception Profile for Children Scores (Harter, 1984)

Group	Pretreatment	Posttreatment
Experimental	$\bar{X}$ 96.73	$\bar{X}$ 97.24
	SD 14.47	SD 13.09
	n = 40	n = 42
Control	$\bar{X}$ 96.06	$\bar{X}$ 98.39
	SD 14.14	SD 13.07
	n = 18	n = 18

Analysis of scores from the Self-Perception Profile for Children (Harter, 1984) indicated no significant difference between the experimental and the control groups at pretest and at posttest. Analysis of the gain scores revealed similar results: no statistically significant change in scores in either the experimental group data or the control group data over the course of the study (Table 8).

Analysis of the scores from the School Science Attitude scale (B.C. Ministry of Education, 1986) indicated that the experimental group and the control group were statistically equivalent at pretreatment and posttreatment measures. Additionally, neither group registered any significant gain over the course of the study (Table 9).

Table 9

Means, Standard Deviations and Numbers for the Attitude Toward School Science Scale Scores (B.C. Ministry of Education, 1988)

Group	Pretreatment	Posttreatment
Experimental	$\bar{X}$ 25.54 SD 5.46 n = 50	$\bar{X}$ 26.98 SD 3.96 n = 47
Control	$\bar{X}$ 25.73 SD 4.20 n = 22	$\bar{X}$ 26.62 SD 4.20 n = 21

Analysis of Qualitative Data

Qualitative data took the form of anecdotal record in the daily record book. The functions of these data are:

1. to directly gauge enjoyment and interest level among students, and

2. to provide insights which might be of value in understanding quantitative results.

The experimental group consisted of two classes: H block and A block. As a result of timetabling, H block was always scheduled for first period of the day. This block occurred five days in seven. The fact that the senior grades (11 and 12) ran on a modified 5 x 7 / 5 x 8 timetable created an interesting situation. School started for all students every day at 8:30. At this time student attendance was taken and morning announcements were broadcast with this "small h-block" ending at 8:45. On two days out of seven, students would then proceed to another class; however, on the five days when chemistry was the first class of the day, there was a 15-minute time slot available up to 9 o'clock which was used by semestered classes. This time slot was a mixed blessing. It could not be used for chemistry teaching since H block students would then be exposed to 25% more instructional time than either the A or D block classes. Consequently, it was used for homework or for errands such as returning library books. The negative part of the 15-minute time slot stemmed from the fact that some 25% of the class were not oriented to morning activity. Although they did arrive, they had significant difficulty arriving before 9:00 a.m., when class would start. This resulted in getting to know a certain group of students in a less than positive sense, the result of which somewhat dulled the teacher's enthusiasm on some days and perhaps had a dulling effect on the remaining 75% of the H block class who were almost invariably enthusiastic to the point that they often had to be restrained from starting chemistry class early.

The A block class was scheduled twice at mid-morning (in a 3-period morning), twice immediately after lunch (in a 2-period afternoon) and once at the last period of the day. Only one student had attendance problems and a generally poor attitude toward school. This class was characterized as an enthusiastic group who, except for times when the classroom temperature soared to 35 degrees celsius, always appeared interested in the course of study. The control group, the D block class was scheduled into chemistry once at mid-morning, once immediately before lunch, once immediately after lunch, and twice last period of the day. Despite the potential problems associated with this timetable scheme (hungry before lunch and tired at the end of the day), the group maintained a positive though often "business as usual" attitude. Students gave the impression that while they didn't mind being in class that many would just as well prefer to be elsewhere. Enjoyment among students in the control group came more from the jokes and prattle of students than from prescribed curriculum activities.

Summary of Results

Results of this study supported the hypothesis that hands on activities may:

1. contribute toward a significant increase in cognitive development, and
2. enhance student interest and enjoyment in Chemistry 11.

Both groups, the experimental and the control, were statistically equivalent on all pretreatment and posttreatment measures at the 0.05 level. Further analysis of the data derived from the Arlin Test of Formal Reasoning (Arlin, 1984) (Table 10) illustrated some interesting trends in terms of the gains made by both groups. No gain was recorded for either group at the high formal level. The vast majority of gains were made among the high concrete and transitional students who moved up to the transitional and low formal levels.

Affective results indicated differences in orientation between the experimental group who derived enjoyment and interest from the work at hand, and the control group who generated its enjoyment from activities which were focused on individual student personalities. Both student self-perception, as measured by the

Table 10

Number of Students and Percentage of Sample at Each Cognitive Level

Group		Concrete (00-07)	High-Concrete (08-14)	Transitional (15-17)	Low Formal (18-24)	High Formal (25-32)
Experimental	Pre (n=43)	0 (0%)	5 (12%)	12 (28%)	16 (37%)	10 (23%)
	Post (n=43)	0 (0%)	3 (8%)	2 (5%)	24 (62%)	10 (26%)
Control	Pre (n=20)	0 (0%)	4 (20%)	6 (30%)	5 (25%)	5 (25%)
	Post (n=20)	0 (0%)	0 (0%)	3 (15%)	12 (60%)	5 (25%)

Self-Perception Profile for Children (Harter, 1985), and student attitude toward science, as measured by the School Science Scale (B.C. Ministry of Education, 1986), indicated no significant longitudinal gain.

Chapter 5

Interpretation of Results

Introduction

The independent variable in this study was the use of hands on teaching strategies. The potential effects of this experimental treatment led to the consideration of five research questions:

1. Would differences in student achievement exist between the experimental group and the control group as measured by pre-treatment/post-treatment scores on Chemistry 11 academic achievement tests?

2. Would differences in student cognitive level exist between the experimental group and the control group as measured by pre-treatment/post-treatment scores on the Arlin Test of Formal Reasoning (Arlin 1987)?

3. Would differences in student self-concept exist between the experimental group and the control group as measured by pre-treatment/post-treatment scores on the Self-Perception Profile for Children (Harter, 1984)?

4. Would differences in student attitude toward science exist between the experimental group and the control group as measured by pre-treatment and post-treatment scores on a British Columbia Ministry of Education Science Attitude Scale (1986)?

5. Would differences in student enjoyment/interest exist between the experimental group and the control group as measured by an assessment of student classroom behaviors (anecdotal record) during the study?

Pretreatment/posttreatment objective data and an ongoing subjective record of comments and impressions were analyzed to seek answers to these questions. Objective data were generated by pretreatment and posttreatment measures of academic achievement, cognitive ability, self-concept and attitude toward science. Subjective data were generated by analysis of the teacher's anecdotal record and student comments to develop an impression of class interest/enjoyment.

This study found that the experimental group scored just as high as the traditionally taught group ($p = 0.05$) on measures of academic ability, student self-concept and attitude. The experimental group showed no less growth in cognitive ability than the traditional group and appeared to enjoy the course content. The experimental group registered a significant change in cognitive ability not registered by the control group; however, this may well have been an artifact resulting from the difference in sample sizes between the experimental group ($n = 50$) and the control group ($n = 24$).

Traditional teaching strategies used in Chemistry 11 appear to be more effective for formal operational learners. In a typical grade 11 chemistry class, approximately 50% of the students think at the concrete operational level. As a result, a significant portion of students is placed in an incompatible learning situation when asked to deal with formal operational scientific thought, concepts, and instructional approaches.

Concrete operational students respond favourably to teaching strategies which involve concrete hands on experiences of the type used in this study. The Chemistry 11 curriculum included a number of key concepts that were classified as having formal cognitive demand. However, the cognitive demand of a concept depends in large part on the manner in which the concept is presented.

Teaching strategies can be designed which present formal concepts in such a way that they become more concrete, and which present concrete concepts in a concrete fashion. Use of these strategies contributes toward a better match between the cognitive demand of a concept and the cognitive ability of many chemistry students. There is no suggestion in the literature that the use of concrete strategies in any way detracts from the learning of formal operational students. Strong evidence exists that all students benefit both in the cognitive as well as in the affective domain. It is likely that formal operational learners when learning concrete concepts continue to utilize their own strategies while subsuming those used by concrete operational learners.

Much current classroom teaching practice which claims to involve students in worthwhile concrete experiences does so only in a superficial sense. Such practices involve the use of traditional laboratory investigations, film or video presentations and teacher demonstrations. These activities for the most part simply represent another way of telling students what they are supposed to know or of verifying that what they had been told was true. In addition to failing at reducing the gap between cognitive demand and cognitive ability, these superficial activities deny students the joy of personal discovery that may result from a guided and well-planned hands on activity.

Cognitive Demands of Traditional and Experimental Approaches

The Chemistry 11 topic "Heating Curves" will serve to illustrate the difference in cognitive demand placed on students using traditional teaching strategies and using hands on strategies. Shayer and Adey (1981) produced a taxonomic system to differentiate the cognitive demands of curriculum into six categories: pre-operational, low concrete, concrete, high concrete, low formal and high formal. Arlin (1984) indicated that the results of Shayer and Adey's work showed close (0.8 to 0.9) correlation with the norms established by Arlin for the Arlin Test of Formal Reasoning. The cognitive demands of the learning/ outcomes pertinent to "The Melting Temperature of a Pure Substance" (Laboratory Text for: Chemistry an Experimental Science, 1963, p. 4) as drawn from the Chemistry Eleven (Province of British Columbia Ministry of Education, 1977) are listed in Table 11, Cognitive Demand of a Traditional Heating Curve Investigation.

Table 11

Cognitive Demand of a Traditional Heating Curve Investigation

	Learning Outcome	Level of Cognitive Demand
1.	The student should know the meaning of: observation, description, interpretation and theory. (p. 1)	Concrete
2.	Identify, locate and properly use the equipment available in the laboratory. (p. 5)	Concrete
3.	Graph measured data and recognize the relationships represented such as direct variation and inverse variation. (p. 5)	High Concrete/Low Formal
4.	Specify properties of matter in its three states: - solids in terms of density, hardness, malleability, lustre, etc. - gases in terms of the gas laws ($PV = nRT$). (p. 5)	Concrete/Low Formal
5.	Give some indication of the amounts of energy involved in changes of state. (p. 5)	Low Formal
6.	Appreciate some of the requirements for theoretical models which attempt to explain the structure and properties of matter.	Low Formal/High Formal

It must be stressed that these learning outcomes, two of which were concrete, one concrete/low formal, one high concrete/low formal, one low formal and one low/high formal had to be met by all chemistry students in this study. However, each group arrived at that point by different means. The control group was given explicit instructions on the laboratory exercise, then carried out a traditional experiment--The Melting Temperature of a Pure Substance (Laboratory Text for: Chemistry an Experimental Science, 1963, p. 4). A consideration of the three questions from the end of this exercise serves well to illustrate the potentially daunting task that faces a concrete operational thinker:

Questions from the "Melting Temperature of a Pure Substance" (Laboratory Text for: Chemistry an Experimental Science, 1963, p. 4)

1. "What effect would increasing the amount of paradichlorobenzene have on the shape of the heating and cooling curves?" (p. 6)
2. "Based on your data what is the freezing temperature of paradichlorobenzene?" (p. 6)
3. "Why do the heating curve and cooling curve have the characteristic shape shown by your graph?" (p. 6)

Classroom experience with this exercise (which was used as an introductory, information gathering experiment) and the questions which follow it highlight flaws which appear to indicate that the concrete operational student was not considered when the exercise was designed. Classroom experience indicates that many students have difficulty getting over the hurdle of the name paradichlorobenzene (moth flakes) and have problems accepting the idea that a substance will freeze at a temperature well above the point at which they normally think of the phenomenon occurring. Students are familiar with ice, water and steam and in an initial investigation of heating curves they appear to respond more favourably to the use of ice as the substance to be heated. Furthermore, laboratory time constraints and the accumulation of fumes in the classroom prevent students from using large quantities of moth flakes and seeking a hands on solution to the question concerning how the shape of the heating/cooling curve could be altered. The phrase "based on your data" (p. 6) is difficult for students to grasp and results (as with the name-paradichlorobenzene) in an unnecessary hinderance to learning. The "characteristic shape" of the graph is seldom generated by students without a verbal harangue on the part of the teacher. Why attempt to generate an idea curve in the first place, particularly in less than ideal circumstances using far less than ideal apparatus? A non-ideal curve is a curve for which students feel ownership since they discovered it, and it works very well to lead into an answer on the third question about characteristic shapes of heating/cooking curves. When the answer to this question is reviewed during the following class, it is a relatively simple matter to show how and why the students' non-ideal graph differs from the ideal because they have personal experience with the factors which contributed toward the non-ideal curve. (The problems associated with this formal activity do not appear to be allayed by using it as a verification exercise following a theory session, as it was supposed to be used originally.)

Experimental and Control Activities Contrasted

The experimental group activity consisted of being told by direction on a sheet of paper that they were to take a sample of ice, heat it to boiling and record their results in the best way possible. Questions on the student instruction sheet guided the inquiry. The questions were:

1. What happened to the temperature of the ice?
2. Why?
3. Was this always happening?
4. Why?
5. What is happening to the ice?
6. Is this always happening?
7. Can you make it happen faster?
8. How?
9. Can you make it happen slower?
10. How?

11. Was ice present at 0^{0}, 50^{0}, 100^{0}?
12. Did the water get hotter after it boiled?
13. If it didn't get hotter, why didn't it if you were still heating the water?
14. What is steam?
15. What is steam made of?
16. How can steam be turned back into water? (Don't use the term condensation.).
17. Are steam and water the same thing?
18. Are steam and ice the same thing?
19. Why will pop stay cold on a hot day as long as there is some ice in it; even a little?
20. What takes up most space, water or steam?

The experimental group questions above related to a substance--ice--with which all students were familiar, they all involved direct observation or as in question 19, an appeal to personal experience, and were phrased for use in introducing a topic; in simple language.

The use of initially simple language coupled with guiding questions which appeal to experiential knowledge will potentially "lure or tease learners into action and to new levels of thinking and understanding" (Yore, Beugger, Romance & Shymansky, 1987, p.). This process represents a promising teaching strategy called scaffolding which is a "process that enables a child or novice to solve a problem, carry out a task or achieve a general goal which would be beyond his unassisted efforts" (Wood, Bruner & Ross, 1979, p. 90). As learners become more familiar with a topic, technical vocabulary and more formal concepts can be introduced in a process known as de-scaffolding.

Students in the experimental group readily moved about interacting with their peers and soon worked at a best method of presenting the data. In addition, several students in this group recorded qualitative observations, and since the quantity of ice was not dictated some students took far longer than others to complete the heating. This extended time required by some students to finish the exercise was a perfect demonstration of one way in which to change the shape of the curve, since the slope of their curve was relatively flat.

This introductory lesson was used as a reference point in the next day's discussion, and was used to build toward fulfilling the ministry learning outcomes (Table 11). The experimental group appeared to have a far easier time remembering and understanding the introductory activity while the control group appeared to become entangled by the application of a heating process to a strange substance. Furthermore, it took considerable effort to explain the meaning of the third question from the laboratory text, "Why do the heating curve and the cooling curve have the characteristic shape shown by your graph" (p. 6), since this question is far too open ended for the concrete operational learner. Several control group students failed to attempt this question. This failure on the part of some students serves as an indicator of the behaviours that thoughtless teaching can encourage.

Implications for Effective Science Teaching/Curriculum

Several issues which have direct implications for effective science teaching and curriculum were suggested by this study. The issues involve the teaching/learning cycle, scaffolding and the generation of student conceptual change.

Learning Cycles

The experimental activities used in this study substituted for different phases of a teaching/learning cycle. However, convincing evidence exists that hands on inquiry centred activities may be of increased value when used in the "learning cycle" developed by Karplus in the early 1970s for use in science education (Birnie, 1984). Birnie cautioned against the notion that the learning cycle is a panacea but suggested that it offered a high probability of success. The learning cycle is a three-phase method of teaching where the hands on activity always occurs at the first phase as a discovery exploration. It consists of a data collection phase (exploration), a phase in which the concept is developed (conceptual invention), and a phase in which the concept is applied in a variety of ways (expansion of the idea). Research indicates this is a very successful approach to teaching in the natural sciences (Renner, Abraham, & Birnie, 1985). The learning cycle approach to teaching has much to recommend it in terms of exemplary science teaching, particularly for concrete learners who may be unable to guide their own discoveries and manipulate abstractions. Little argument exists against the notion that "instructional strategies utilized to teach science concepts are most effective when they consist of activities which serve three functions:. (1) to introduce the concept, (2) to discuss the concept, and (3) to apply the concept" (Abraham, 1988, p. 4). The learning cycle uses all three phases; but more importantly, it ensures that laboratory activities which are guided inquiry centred activities are always used in phase one, to introduce the concept. In this position, the student is always moving from data derived from personal observation toward the concept. This sequence from data toward concept allows the student to build an understanding of a concept based on prior conceptual knowledge. Placing a hands on activity at the start of a teaching/learning cycle affords additional opportunity for students to experience the joy of personal discovery since they have heard no teacher-explained theory which might serve to cloud their natural judgement or cause them to lose interest because they have been told what will happen in the experiment. As Yore (1986) suggested, the function of the teacher during these activities is to move around among students and guide their thinking by asking thought provoking questions which focus student attention on unnoticed data. These inquiries enhance student autonomy, confidence and enjoyment resulting in a classroom situation where discipline problems are minimized as a result of maximizing meaningful student engagement and interest in personal discovery.

Scaffolding

Students do not need to be hindered by needless terminology. It is impossible to deny that science has a rich and very specific vocabulary but there is a time and a place for both the complex vocabulary and the concepts which generate the vocabulary. It is unnecessary and counterproductive to consider new concepts and use new vocabulary at the same time. Yore (1987) stated that "Language must be interwoven with activity, at times language leading activity and at other times activity leading language but always interdependent" (p. 3). Yore (1987) suggested that a "strategy must lure or tease learners into action and to new levels of thinking and understanding" (p. 3). The results of such strategies tend to encourage students to be more self-regulated, cooperative, creative and rational learners. Other major benefits of scaffolding derive from helping learners organize, analyze, and generalize patterns which can be applied to and integrated with prior conceptual knowledge. Yore (1987) continued that: "The teacher must design learning experiences rich in verbal language, activity and social interaction that engage learners, provide appropriate experience and encourage learners to organize and restructure their understanding" (p. 3). Having assimilated the new concept in terms of prior knowledge, the learner will be in a position to accommodate readily the more advanced technical vocabulary associated with the topic and will be in a state of cognitive readiness to study realistic applications. At this point, students will naturally begin to de-scaffold as they master the intellectual skills required to structure and regulate their own inquiries.

Conceptual Change

The ability to inquire systematically and logically represents a powerful learning tool throughout life. Consequently, the teaching of critical inquiry thinking (observe-hypothesize-test) must stand as one of the most important content goals of education. Students who have mastered the skills associated with critical inquiry thinking are admirably well equipped to direct their own learning, and, as a result, have become educationally autonomous and self-regulated. A question must be raised how many individual science topics must be included in curriculum in order to generate autonomous critical thinking in students. Penick and Krajcik (1984) suggested that evidence indicated the number of topics covered in chemistry courses was greater than necessary.

> We would like to see more focus on fewer ideas, as well as on the integration of those ideas with the reality known by students. Making these connections between chemistry and the students' knowledge will help students see the concepts and principles much more clearly. (Penick & Krajcik, 1984, p. 48)

Too many topics tend to fragment student learning, giving the learner the impression that the scientific endeavour is highly fragmented. Under these circumstances, students will not recognize that topics can be organized into a rational pattern. Classroom experience indicates that the ability to recognize patterns may lead to valuable cognitive insight and facility with subject matter. Combining the development of critical inquiry and reducing the number of topics while stressing connections between topics and real life may result in a situation where students can begin to piece together a realistic impression of science, society, and their place in it.

Implications for Future Research

The hands on activities which represented the independent variable in this study were generated out of necessity. Teaching strategies which had been judged appropriate up to the 1985/86 academic year were subsequently judged inappropriate. Development of the activities stemmed from the need to appeal to what was apparently a broader range of student abilities in this investigator's Chemistry 11 classes. The broader range of student abilities was attributed to the 1984 decision by the British Columbia Ministry of Education that all students must take a senior science course as a graduation requirement. Chemistry enrolment which had heretofore fluctuated by ± 10% annually, increased by 25% and remained at that level during the following year in the school where the study was conducted. While chemistry enrolment increased by 25%, tutorial hours increased by 400%. It was on the basis of these discrepant numbers that the new teaching strategies were judged necessary.

As a result of favourable student comment on some of the activities as they were used in tutorials, and a feeling on the part of the teacher that his classroom teaching was missing some students, the activities were integrated into the Chemistry 11 course. They were used as necessary and where necessary in this study.

An improved research design would have involved equal size experimental and control groups. Furthermore, a means of individual student identification on pre-treatment/post-treatment test instruments should have been devised while maintaining student anonymity in order to measure covariance and strengthening the quantitative data. Much comparison is made between the hands-on activities and traditional laboratory exercises. Since traditional laboratory exercises represent a verification or second phase in the traditional instruction-verification-expansion teaching/learning cycle and were designed to have the greatest effect following a traditional lecture session, how can valid comparison be made between a hands on activity used as an instructional phase of a teaching/learning cycle and a traditional laboratory exercise that has been transplanted to become an introductory exercise? The answer to this question must be that comparison is limited; traditional science teaching is not without its time honoured successes. Perhaps a more meaningful study would have involved a comparison between two groups where one group was taught a content area by purely traditional methods and one is taught using a consistent experimental approach such as the learning cycles laboratory-instructional approach.

Recommendations

It was felt that the data collected and the results of the analysis of this limited study justified a number of recommendations. It is recommended:

1. That further research be conducted to determine the cognitive abilities of Chemistry 11 students.

2. That the cognitive demands of the Chemistry 11 learning outcomes as commonly taught be analyzed.

3. That a concerted effort be made to match the cognitive abilities of Chemistry 11 students with the cognitive demands of the course.

4. That the Ministry of Education undertake a program to identify the concrete teaching strategies most appropriate to Chemistry 11 students.

5. That exemplary chemistry teachers in British Columbia serve as resource people for development of a new Chemistry 11 concrete teaching perspective.

6. That information on the teacher and student benefits from exemplary teaching be disseminated among practising teachers as well as teachers in training.

7. That exemplary science teachers be invited to train prospective science teachers at various teaching colleges.

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ISBN 0-315-53717-5

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