CONCEPTIONS OF EXPERIMENTATION DURING A SCIENCE FAIR: A CASE OF FOUR SCIENCE NINE/TEN HONOUR STUDENTS

by

Wayne Lau

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B.Ed., University of British Columbia, 1990

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Abstract

This exploratory case study documented the conceptions of experimentation of four Science 9/10 honour students prior to, during, and after their participation in a science fair that took place in a high school setting. The four student participants consisted of: a male and a female student with experience in a science fair, and a male and a female student with no experience in a science fair. The data for this study were the students' journals and responses to a questionnaire, and in-depth phenomenological interviews.

At the start of the science fair, all four students had an everyday sense of experimentation: trying or carrying out a procedure and learning from the experience. One of the four students also had a scientific sense of experimentation: identifying variables and figuring out the procedure to solve a problem. As the students worked on their science fair projects, they reiterated their initial conceptions of experimentation. The students also elaborated on their conceptions by adding that experiments: can be "formal" or "informal," answer questions, involve "creativity," and are a part of a learning process. By the end of the science fair, all but one of the students kept their initial conceptions of experimentation.

Documenting the above students' conceptions of typical science classroom activities, such as structured laboratory activities and demonstration, was also an integral part of this study. In general the students' thoughts on the above activities were similar to their conceptions of experimentations. The greater the amount of hands-on involvement and input to the procedure from the student, the more likely the students considered the activity an experiment.

An examination of the type of investigation the students' conducted for their projects showed that three of the projects could be classified as the engineering model of experimentation while the fourth project could be classified as the science model of experimentation. The above classification provided insight on the rationales behind the students' conceptions of experimentation.

This study has implications for both teachers and researchers. Specifically, it implies that students have ideas about experimentation and these ideas need to be incorporated in science classroom activities and the students' own investigations. By deliberately engaging students to think about the nature of science and scientific inquiry, students can move towards scientific experimentation.

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CHAPTER 1

The Research Problem

"Science is a special kind of story-making, with no right and wrong answers, just better and better stories. You live with the best story you have at the moment" (Rowe, cited in Fisher, 1992, p.53).

I. Introduction

The focus of this study was on four of my Science 9/10 honour students' conceptions of experimentation during a school held science fair. The idea for this study came from three main sources: 1) the goals of the 1985 British Columbia Junior Science Curriculum[1] , 2) an examination of the literature on students' science conceptions, in particular experimentation, and 3) my own experience as a graduate student and teacher. In this chapter I will frame my research problem and give the reader a sense of the evolution of this study.

One of the four goals in the 1985 B.C. Junior Science Curriculum Guide is to "provide opportunities for students to develop the skills and processes of science" (Ministry of Education, 1985, p.5). To achieve this goal, the curriculum guide lists the following opportunities that "should be provided" to the students: observing, classifying, quantifying, communicating, inferring, predicting, interpreting data, formulating hypotheses, controlling variables, experimenting, defining operationally, and formulating models. However, the above elements of scientific experimentation are conceived from the point of view of a community of educators. A student who conducts science activities may have a different perspective on scientific experimentation. That is, one may think of experimentation in the everyday sense and experimentation in the scientific sense. Conant (1957) differentiates two kinds of experimentation as follows:

1 The 1985 BC Junior Science Curriculum was in effect during the conception and data collection phases of this study. At the writing of this thesis, that curriculum was replaced by the Science 8 to 10 Integrated Resource Package 1996.

> The difference between experimentation in everyday life and experimentation in science lies primarily in the fact that in the one case common-sense assumptions and practical experience determine the nature of the experiment; in the other, a series of connecting links usually relates some deductions of a broad working hypothesis with the final limited working hypothesis involved in the specific experiment (p. xiii).

Thus the scientific sense of experimentation is purposeful inquiry guided by scientific laws, assumptions, and procedures. The everyday sense of experimentation is more pragmatic, less structured, and less rigorous than the scientific sense.

The 1985 B.C. Junior Science Curriculum, however, does not directly address how the two kinds of experimentation may complement, enhance, or conflict with the meaning of experimentation students bring to the classroom. Since "personal experience and understanding are essential to our understanding of scientific phenomena" (Wideen et al., 1992, p. 37), it is within a constructivist perspective of learning to acknowledge that students come to the classroom with ideas about what is an experiment. The aim of this study was to investigate four Science 9/10 honour students' conceptions of experimentation at the start of the school year and throughout their involvement in textbook lab activities and a science fair.

II. Structured and unstructured activities

My Science 9/10 honour course (the setting for this study) uses a combination of structured (textbook laboratory work) and unstructured (science fair) activities to achieve the goals in the curriculum guide. The 1985 B.C. Junior Science Curriculum Guide describes the extent an activity is structured or unstructured:

> In well-conceived structured activities, the student is told how to gather the data and perhaps even how to present it. However, the student does not know in advance what the results will be. After data has been gathered, leading questions may be asked to aim the student in the direction of a reasonable analysis of the data and a desired generalization (p. 140).
>
> A completely unstructured activity merely poses a problem and then allows students liberty to devise their own procedure, organize their own data, and arrive at their own generalizations (p. 140).

If a greater onus is placed on the student to think and work through an unstructured activity than a structured activity, then the interaction, if any, between these two types of activities on a student's conception of experimentation should be examined.

Textbooks

One ready source of structured and, to a lesser extent, unstructured activities is the textbook. Science textbooks serve a number of purposes in science classrooms. Some of the roles these books have include defining, illustrating, and integrating concepts. Textbooks also serve as a convenient source for 'quick' and 'safe' laboratory activities to supplement the concepts taught in the classroom. In a typical textbook laboratory activity, the textbook provides the students with the purpose, list of materials and procedure for doing the activity, and questions about the activity. However, by providing 'recipes' for students to follow, the amount of student intervention, for example altering a procedure to test a student's idea, is minimal.

In a scientific skills study using the Laboratory Structure and Task Analysis Inventory on some of the most widely used science textbooks in Canada, Souque (1987) reports that

> the laboratory exercises were almost always highly structured and only low-level tasks were required from the students. Out of the 32 textbooks examined, 28 of them never asked the student to formulate a question or define a problem, and the student was only rarely asked to plan the observation or measurement procedure or determine the accuracy of the results, and even more rarely to plan the experiment (p. 80).

Given the above finding, the frequency with which textbooks are used in classrooms need to be examined. This is because if text based lab work is frequently assigned, then students may understand science investigations as just following others' work.

The 1991 B.C. Assessment of Science Technical Report I indicates that the higher the grade level, the greater the number of teachers who reported "frequently" the use of the lab centred (9% in Grade 4, 15% in Grade 7, 54% in Grade 10) and text-based (22% in Grade 4, 33% in Grade 7, 58% in Grade 10, (p. 282)) approaches as instructional strategies. Thus if the bulk of a student's experience in doing science is from these structured activities, then it is important to explore students' conceptions of experimentation so that any necessary preparation and support can be given to the students when they work on unstructured activities in order to meet all the opportunities that should be provided to the students.

Science fairs

The textbook is certainly not the only source of instructional strategy available to a teacher. In an effort to promote interest in science and to challenge students beyond the classroom setting, a number of science competitions (The Greater Vancouver Regional Science Fair, Technolympics, and Physics Olympics) occur annually in the Lower Mainland of British Columbia. In a science fair, students are encouraged to investigate their own questions and present their findings to judges. Science fairs are considered unstructured activities because the students are given a greater responsibility to complete, on their own, every step of their investigation: from defining the problem, to developing and carrying out the procedure, and making their own conclusions.

If a student were to engage in both an unstructured science investigation such as a science fair and textbook structured laboratory activities, then it is important for teachers to examine the effects, if any, these two types of activities have on students' conception of experimentation. However, I have found no published study that examined this specific issue. Thus one of the research questions in this study addresses whether students consider structured lab activities as experiments.

III. Two stories

The metaphor of science as a never ending story in the opening quotation is an interesting one. In a science story, as in an adventure, one never knows with absolute certainty what may lie ahead. Thus, when one omits the process of a scientific investigation and looks only at its product, science may seem as if it were magic. The process and its product must be examined together. Because this study focuses on only four students from my science class, the context surrounding this study is just as important as the results of the thesis. Therefore, the reader will find two distinct stories herein. One story is about my journey in learning about scientific experimentation and how the journey evolved into this study. The other story (Chapter 4 - Results) is about the four students and their conceptions of experimentation during a science fair.

My experience in experimenting (I)

One of the curriculum orientations is the development of cognitive processes (Eisner & Vallance, 1973). This approach places the teacher in the role of a guide, a facilitator, and a resource person to help students learn how to learn. However, as McNeil (1977) points out, "teachers who themselves had never produced knowledge - who had not made an original scientific finding or historical interpretation - had difficulty leading students in the ways of discovery" (p.58).

Even though I teach science, I have never conducted the type of unstructured activity such as that required of the science fair. In my high school and undergraduate science courses, most of the laboratory activities were of the recipe type. A typical lab consisted of a purpose, step-by-step instructions, and questions for me to answer. I had never completed an unstructured investigative activity such as a science fair. Also, unlike the four students in this study, I did not think about the meaning of an experiment while I was conducting those lab activities. Therefore, my own conception of experimentation was one dimensional - based only on experience with rigidly structured lab activities. It was not until I began teaching and during graduate studies that I became more aware of the purpose of experimentation, and its role in the production of scientific knowledge.

It was during a course on the epistemology of science that I began to grapple with my lack of understanding of the epistemology of an experiment. In one of the course activities, the professor asked the class to find out as much as we could about a computer generated enigma using only our knowledge of science, a minimal number of tools available on the computer simulation, and minimal directions from the instructor. It would be too lengthy to go into the details of the activity here. Suffice to say that the experience taught me that experimentation is more than just following a recipe and looking for the right answers. To experiment is also to think about the production of knowledge.

The next highlight of my graduate work and understanding of students' conceptions of experimentation came when I taught the Science 9/10 honour course for the first time. For one of my graduate courses, I conducted a small study on my first year's Sc 9/10 honour students' understanding of the term 'experiment.' That study surveyed the students about their conception of an experiment before and after their exposure to a computer simulation on carrying out controlled experiments. In the simulation, the students had to work through progressively more complex experiments that required controlling more variables to answer a question.

In that study, the students tended to equate experimenting with "finding out," "discovering," and "learning" new things. I received many interesting written comments. Most of the students thought that scientists experimented until they had the answer(s) they wanted. Many students did not consider school experiments to be the same as scientists' experiments because scientists have better, more elaborate equipment. Lastly, perhaps due to the novelty of using computers in a science class, almost all the students recommended the computer simulation to future science fair students to learn about controlled experiments. However, that was not implemented during this study because the computers were replaced, and the software could not be used with the new computers.

From the above students' responses, I learned much about their meanings of experiment. Some of the changes I made to the second year of the course (this study's time frame) were based on the comments on, and results of, that study. For example, I asked my students for more detailed recordings of the students' thoughts and actions in their journals so that I could have a better understanding of their science fair progress. Also, more group discussion on the science fair was incorporated into the course to facilitate the students sharing their ideas, problems, and research findings. For me, one question which emerged from the study was whether the students' conceptions of experimentation would change over the length of the science fair. This question was examined in the current study.

That first science fair was a learning experience for me in another way. The question of whether or not a demonstration is an experiment never occurred to me until some of the students conducted demonstrations (to show a theory, principle, or law) for their science fair projects. Even though the science fair emphasized the scientific experimentation approach, some of the students felt that since they built their projects and tested them until they showed the desired effect, their projects were more like an experiment and less like a demonstration. At that time, the students had already completed their projects. Therefore, I suggested to those students that they should make explicit, in their reports and to the judges, the problems they had and how they went about solving those problems to make their projects 'work.' Since I was interested in the students' choice for a science fair project, another research question in this study was: What are students' conceptions of demonstrations as experiments?

IV. Purpose of the study

This study was the culmination of a number of personal experiences as a high school teacher and a graduate student. The purpose of this study was to investigate four Science 9/10 honour students' conceptions of experimentation during a science fair. There were several reasons for this research. As a teacher of these students, I believed that a better understanding of what the students perceived as an experiment is important in the planning, implementation, and evaluation of my classroom practice. Also, the effects of structured and unstructured investigative activities on students' conceptions of experimentation needed further examination. Another goal of this study was to share with the reader a sense of my own 'experimenting,' as a teacher and researcher, in the evolution of this study.

Research Questions

Three concerns arose from the above examination of structured and unstructured investigative activities and how students' conceptions of experimentation may be changed by these two types of experiences. I examined the following research questions to address the above concerns.

General research questions:

1. What are four Science 9/10 honour students' conceptions of experimentation at the start, during, and following a science fair?
2. What is the relationship between these conceptions of experimentation and the students' conceptions of typical science classroom activities?

Sub-questions:

a) What are the students' conceptions of structured laboratory activities as experiments?

b) What are the students' conceptions of demonstrations as experiments?

Limitations of the study

This was a year long exploratory case study where the major objective of the research was to identify the students' conceptions. A number of limitations existed in this study. First, the sample size of four honour Science 9/10 students was representative of a very narrow segment of the student population. All the students involved in this study came from one class in one secondary school. Also, these students were required to participate in a science fair which may not be the condition in other school settings. The fact that the researcher was also the students' teacher undoubtedly had an effect on the students' responses to the data collection instruments and interviews. The timing (after school), length of the interviews (about 45 to 60 minutes), and my interviewing skills could have affected the quality of the interview data. However, the variety of data and data collection strategies (student journals, questionnaires, and audio tape interviews) and the length of the study acted as triangulation in the data analysis.

Educational significance of the study

The results of this study will extend the present understanding of students' conceptions of 'doing' science, in particular, unstructured experimentation such as a science fair. If students find science fair experiments to be more similar to their own conceptions of experimentation than textbook structured experiments, then teachers might consider incorporating more unstructured activities such as science fairs into their instructional strategies. Additionally, science fairs can facilitate the integration of various disciplines like Mathematics, Science, and English. For example, a science fair requires the students to devise and conduct their own investigations, design and construct displays, and report (in writing and orally) on their findings. All of these activities require knowledge and skills from various disciplines.

V. Summary

This chapter provided the reader with the background and rationale for this study. Given that students come to the classroom with an everyday sense of experimentation, I reasoned that the structured and unstructured experiences I provided to my students may have an interaction with the students' conception of experimentation. Thus this study investigated Science 9/10 students' conception of experimentation during a science fair. The data used in the analysis were the students' journals, questionnaires, and audio tape interviews. The goals of this study were to: research and reflect on my classroom practice and add to the current understanding of Science 9/10 students' conceptions of experimentation.

VI. Overview of the rest of the thesis

In Chapter two, I will present a general overview of constructivism, students' conceptions of science concepts, how the term 'experiment' is used in the literature and recent studies on student experimentation. In Chapter three, I will describe the methodology of this study, the context, and the students. Also, I will discuss the theoretical framework for data analysis. In Chapter four, I will discuss the results of this study. The results will be presented as cases. Data from the students' journals, interviews, and questionnaires will address the research questions. In the concluding chapter, I will summarize and discuss the results. Implications for educators will be suggested.

CHAPTER 2

Literature Review

> "The purpose of scientific enquiry is not to compile an inventory of factual information, nor to build up a totalitarian world picture of natural Laws in which every event that is not compulsory is forbidden. We should think of it rather as a logically articulated structure of justifiable beliefs about nature. It begins as a story about a Possible World - a story which we invent and criticize and modify as we go along, so that it ends by being, as nearly as we can make it, a story about real life" (Medawar, 1969, p. 59).

The purpose of this chapter is to give a general overview of constructivism, students' conceptions of science concepts, how the term 'experiment' is used in the literature and its associated meanings, and studies on students' conceptions of experimentation.

I. Constructivism

Philosophies of science

A constructivist philosophy of science asserts that knowledge is a construction of the mind. According to this view "nature as such does not have laws, but its behaviour can be described and predicted on the basis of laws and theories formulated by scientists" (Nadeau & Désautels, 1984, p. 27). Thus knowledge is not confirmable nor provable but pragmatic and tentative in that "constructivism presupposes that theory precedes observations, and that observations can be selected and conducted only through theoretical expectations" (Nussbaum, 1989, p. 531). This is in contrast to other philosophies of science such as: empiricism - positivism and rationalism.

Empiricism-positivism and rationalism hold that there is an absolute truth and what has been proven or confirmed is called 'knowledge.' Empiricism-positivism differs from rationalism in that the former relies on sense data and logic as evidence while the latter relies on the strengths of one's argument and intellect (Nussbaum, 1989).[2] Later in this chapter, I will

[2] Nussbaum (1989) provides a graphical summary of the similarities and differences between the various philosophers and philosophies of science.

discuss how the type of experiments conducted is closely linked with a particular philosophy of science. The next section examines the various labels used to describe students' conceptions by education researchers using a constructivist framework.

Research on students' conceptions

Wideen et al. (1991) claim that Piaget was the one who introduced the importance of children's alternative conceptions in their learning. However, Solomon (1994) credits Driver & Easley's (1978) article[3] for creating the "tools for the accelerated rise of constructivism in science education" (p. 3). As of September 1990, there have been about 2000 empirical and theoretical studies covering the topic of students' conceptions (Pfundt & Duit, 1991). One overwhelming result is that students come to the classroom with ideas about the natural world already in their heads, and these ideas are often different from the scientifically accepted ones.

A review of the literature shows that a variety of terms is used to label the kinds of science conceptions students bring to the classrooms. Some of these terms are: 'misconceptions,' 'alternative frameworks,' 'alternative conceptions,' 'conceptual frameworks,' 'preconceptions,' 'children's science,' 'intuitive ideas,' 'minitheories,' and 'untutored beliefs' (Bell, 1993; Duit, 1991). The above terms indicate that students' ideas are unlike scientists' ideas. In addition, Pfundt & Duit (1991) argue that the number of terms also indicate the variety of theoretical research approaches and that "no 'unifying' theory appears to be in sight" (xlii). I will briefly examine the meanings associated with the labels "misconceptions", "untutored notions," and "children's science." These labels highlight the range of thoughts on the ideas students bring to the classroom.

Driver (1983) writes that interpreting misconceptions as errors or wrong answers may "trivialize the nature of the problem by giving the impression that the source of errors are mislearned 'facts'" (pp. 25-26). She believes that differences between the students' and the

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3 Driver, R. & Easley, J. (1978). Pupils and paradigms: A review of literature related to concept development in adolescent science students. Studies in Science Education, 5, 61-84.

scientific community's conceptual models or frameworks are the sources of students' misconceptions. Driver is not alone in her belief. In fact, most researchers also view students' conceptions as alternative frameworks in their work (Pfundt & Duit, 1991).

Hills (1989), in a review of some of the above terminology and their underlying research frameworks and assumptions, suggests that students' views are similar to scientists' views in an "embryonic sense" (p. 160). That is, students' untutored notions, guided by commonsense theories, can be thought of as some types of primitive or unsophisticated science. Another research approach is to consider children as scientists.

The metaphor of children as scientists is emphasized in the term "children's science" (Osborne & Freyberg, 1985). Within a limited range, children's exploration of the world is seen as resembling those of scientists'. Children's science is described as "the views of the world and meanings for words that children tend to acquire before they are formally taught science. Children's science develops as children attempt to make sense of the world in which they live in terms of their experiences, their current knowledge and their use of language" (Osborne, Bell, & Gilbert, 1983, p. 1). In addition, Duit (1991) asserts that the use of the term "children's science" attaches dignity to students' conceptions.

Despite the various labels used in the literature to describe students' conceptions, several conclusions have been drawn about the conceptions: learners have their own ideas about phenomena, meanings for words, and explanations of why thing behave the way they do; learners' ideas are resistant to change or change in unexpected ways even after formal lessons, and learning is seen as a conceptual change (Bell, 1993; Driver et al., 1994; Kuhn, 1989; Linder & Erickson, 1989).

Criticisms of constructivism

Research efforts based on a constructivist framework have produced a greater understanding of students' science conceptions, and many tools, such as concept mapping, for researching and teaching for understanding (White & Gunstone, 1992). However, concerns about constructivism have also appeared. Solomon (1994) describes constructivism as a language and vocabulary game in which constructivism is a "fruitful redescription" of well known "aspects of the human nature and learning" (p. 1). Millar (1989) raises another cautionary voice by writing that

> (i) The constructivism model of learning has (invalidly) become associated with a particular model of instruction. This association is not logically entailed and may be unproductive.
> (ii) There is a need to reconcile the constructivist emphasis on 'taking learners' ideas seriously' with the fact that science is, at any particular time, almost entirely a body of consensually agreed knowledge.
> (iii) It would be more productive to model understanding as a collection of discrete 'knowledge fragments' than as a 'framework' of ideas and propositions (p. 588).

Despite the above comments, researchers have produced a rich data base of information on learning and students' science conceptions. Their work has also suggested directions for future research such as greater involvement of teachers in research programmes themselves to enhance students' classroom learning (Driver, 1989). This study is another effort to take up on that challenge.

II. Experimentation

Laboratory work

There are many reasons to incorporate laboratory work in the science curriculum. A teacher may use laboratory work to expose students to the methods of verifying or understanding what is taught in the classroom, provide hands-on experience in manipulating laboratory equipment, or engage students in probing their own questions. This mode of 'active' learning is usually thought to help students develop a better understanding of science. However, some of the intuitive assumptions behind laboratory work are questionable. For instance, textbook activities often follow the so-called 'scientific method.' A typical 'scientific method' has the following components: "definition of the problem, observation, gathering of information, formulation of a hypothesis, designing of an experiment with controlled variables, verification, and communication of results" (Souque, 1987, p. 80). The assumption is that scientists also follow the above method in their work. The literature shows otherwise.

Medawar (1969), in describing how scientists carry out their work, states:

> If the purpose of scientific methodology is to prescribe or expound a system of enquiry or even a code of practice for scientific behaviour, then scientists seem to be able to get on very well without it. Most scientists receive no tuition in scientific method, but those who have been instructed perform no better as scientists than those who have not (p. 8).

Conant (1957), Hodson (1993), and Millar & Driver (1987) also echo the above view. Millar and Driver (1987), in their search to find supportive evidence for the 'method of science,' write "that there is almost no support from historians, philosophers or sociologists of science that any such *method* [emphasis theirs] exists, or can be described" (p. 39). "Scientific inquiry appears to be a messy business; good scientists are guided intuitively as to what to do next" (Haysom, 1994, p. 9).

Another assumption for providing laboratory work to students is that 'doing' equates with 'understanding.' However, Driver (1983), Hodson (1993), and Osborne and Freyberg (1985) show that the above view does not always occur in practice. In fact there "is abundant evidence that even directly after completing a conventional practical exercise, many children cannot say what they did, why they did it or what they found" (Hodson, 1993, p. 102).

The work of Osborne and Freyberg (1985) provide some answers to why laboratory work does not always result in understanding. They state that discrepancies between the teacher and the students in intent, action, and views of the world are the obstacles. For examples, students may see lessons as isolated events, establish alternative purposes for an activity, or fail to recognize critical factors in an experiment. The discrepancy that has particular relevance to this study is the 'views of the world.'

Given that research shows that students have ideas about the natural world and they bring these ideas to the classroom, consideration needs to be given to the notion that students' "existing ideas and past experiences can result in their placing quite a different perspective on an activity from that anticipated by the teacher" (Osborne & Freyberg, 1985, p. 75). For instance a teacher may think of an experiment as a tool for students to gather data. However, a student may think of an experiment as an opportunity to learn or to try something with no attention paid to the underlying theory. What are the possible conceptions of experimentation? I examined many sources for the meaning of experiment. What follows is a survey of the literature pertinent to this study and it begins with an uncommon source.

A dictionary's meaning

According to Webster's Third New International Dictionary of the English Language Unabridged (1981), the word 'experiment' has its roots in the Latin word 'experiri' which means to try (p. 800). The following is a list of the dictionary's meanings for the word 'experiment:'

- a test or trial
- a tentative procedure or policy
- an act or operation carried out under conditions determined by the experimenter (as in a laboratory) in order to discover some unknown principle or effect or to test, establish, or illustrate some suggested or known truth
- experience
- expedient, remedy
- the process or practice of trying or testing (p. 800).

School library books on science projects or experiments

Since my students were required to conduct the science fair as an independent project, the school's library was one of their main sources of information on science fair topics and how to carry out a science fair project. The school's library was also one of my sources for the literature review.

I conducted a search for all the science books that contained the word 'experiment' or 'project' in their titles. Nineteen science experiment and 17 science project books were located and reviewed for their explanation, definition, or meaning of the word 'experiment.'

Of the 17 science project books, four do not contain the word 'experiment,' four use the word 'experiment' with no definition given and nine define the word 'experiment.' Of the 19 science experiment books, one uses the word 'investigation' instead of 'experiment,' one does not use the word 'experiment' in the book, 14 use the word 'experiment' without defining what it means, and three define an 'experiment' to the reader. Table 1 summarizes the above findings.

Table 1. Summary of science project or experiment books' (n = 36) use of the word 'experiment.'

Usage of 'experiment':	Science project books	Science experiment books	Total
Does not use or define 'experiment'	4	1 (uses 'investigation' instead of 'experiment')	5
Uses 'experiment' but does not define it	4	15	19
Defines 'experiment'	9	3	12
Total	17	19	36

It is surprising that 19 out of 36 books (53%) use the word 'experiment' without explaining or defining what it is to the reader. It is as though the authors assume the reader has a commonsense understanding of an experiment or will understand it after carrying out the activities. Of the 12 books that define an experiment, the general description of an experiment is a hands-on investigation to test a hypothesis under controlled conditions. However, all 36 books provide recipe-style instructions for the students to follow.

In addition to the above books, the science fair booklet provided by the Greater Vancouver Regional Science Fair was another source for the definition of the word experiment. The 1996 Science Fairs guide defined an experiment as "an investigation undertaken to test a specific hypothesis using experiments. Experimental variables, if identified, are controlled to some extent" (p. 3).

Curriculum guides

The curriculum guides are important resources in assisting teachers in what to teach and how to approach its teaching. The 1985 B.C. Junior Secondary Science Curriculum states that experimenting is "the testing of predictions and hypotheses by designing and carrying out appropriate procedures" (p. 6). The current B.C. curriculum guide defines experimenting as

> a cause-and-effect test between two variables. All processes may be involved. This can begin with setting a problem to be solved, identifying the variables to be controlled, making operational definitions, devising the test to be carried out, and following the prescribed procedure (B.C. Ministry of Education, 1996, p. 5).

In addition to the more detailed definition of experiment in the current guide, another difference is that the current guide states, "following the prescribed procedure" as part of experimenting. The latter has an implication in this study.

If a student were assigned a textbook activity where the procedure is listed and followed, then according to the 1985 curriculum, that activity cannot be considered an experiment because the designing process is absent. However according to the 1996 curriculum guide, following a procedure, as in a textbook activity, would be considered an experiment. Again based on the current guide, if a student followed a procedure demonstrated by a teacher, then that could also be considered an experiment.

Scientists' views

How does scientific thinking differ from everyday thinking? Driver et al. (1994) argue that the two kinds of thinking differ in three ways: the ontological entities they contain, explicitness in rule formulation, and world view. Everyday or commonsense thinking is "characterized by pragmatism" where "ideas that are judged in terms of being useful for specific purposes or in specific situations" (Driver et al., 1994, p. 8). On the other hand "the heart of scientific thinking is the coordination of theories and evidence. A central premise underlying science is that scientific theories stand in relation to actual or potential bodies of evidence against which they can be evaluated" (Kuhn, 1989, p. 674). Thus a child would tend not to include contrived experimental situations when she or he explores his or her world (Bell, 1993).

The kind of science experiment one conducts has to do with one's theory of the role of experiment. Medawar (1969) writes that there are at least four kinds of experiments: inductive, deductive, critical, and demonstrative.

In inductivism, experiments are believed to provide data from which theories and laws are induced. This is similar to qualitative research's 'grounded theory' (McMillan & Schumacher, 1993) where the theory is developed from the data. An inductive experiment might begin with "I wonder what would happen if." This line of questioning derives from Francis Bacon's usage of the word 'experiment.' According to Bacon, to experiment is to contrive experiences and invent happenings (Medawar, 1969). However, Harré (1981) argues that the inductive theory of the role of experiment is mistaken. He claims that an experiment only tests one instance in time whereas laws are universal across time. Therefore, it would take an infinite number of experiments to prove a theory correct.

Deductive or Kantian experiments "examine the consequences of varying the axioms or presuppositions of a scheme of deductive reasoning ('let's see what happens if we take a different view')" (Medawar, 1969, p. 35). Newtonian physics and Euclidian geometry are examples of Kantian experiments where an appropriate application of logic can result in a close approximation to the 'ideal' (Nussbaum, 1989).

Critical or Galilean experiments are actions carried out to test a hypothesis by examining the logical consequences of holding it. Another name for this type of experiment is fallibilism. In fallibilism, a scientist works to find evidence to refute a theory. If an experiment falsifies a theory then that theory should be rejected. On the contrary, the absence of contradictory evidence is support for a theory (McComas, 1996). Adams (1991) writes that

Popper made fallibilism central to his definition of science. Harré (1981) again argues that if an experiment does not support a theory at one time, there is a possibility that the theory could be correct at another place and time. Thus he believes the critical view is not a viable role of experiments.

According to Medawar (1969), a demonstrative or Aristotelian experiment intends to illustrate a preconceived truth or convince people of its validity. For instance, a classroom teacher dissolves potassium permanganate crystals in containers of cold, warm, and hot water in order to illustrate the motion of particles in the liquid state.[4]

So far I have described the types of experiments where there is a physical manipulation of objects or variables. There is another type of experiment where there is no direct physical manipulation but it is also a part of a scientist's tool kit. Gedanken Experimente, or experiments of the mind, are experiments that are easy to conceive but are too difficult, too expensive, or 'impossible' to carry out (Helm, Gilbert, & Watts, 1985). Sorensen (1992) describes a thought experiment as "an experiment that purports to achieve its aim without the benefit of execution" (p. 205). Examples of thought experiments in physics that follow the above description include: Maxwell's demon, Einstein's train, and Heisenberg's gamma-ray microscope (Helm & Gilbert, 1985).

Practitioners' views

Thus far this literature review shows that there are two broad conceptions of experimentation:

1. everyday (commonsense) - where an experiment is a test or a trial and
2. scientific - where an experiment is a contrived (controlled) intervention.

Are these the only kinds of conceptions of experimentation? If the conception of experimentation can be thought of as a continuum with the everyday sense and the scientific sense at two locations along the continuum, what might be in between? Hodson (1993) writes

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4 See Activity 1f "Liquids in Motion" in <u>Science Probe 8</u>, 1985, pp. 22-23.

that "the only effective way to learn to do science is by *doing science* [emphasis his], alongside a skilled and experienced practitioner who can provide on-the-job support, criticism and advice" (p. 120). The idea of a scientist as a practitioner led me to recall Donald Schön's (1983) "The reflective practitioner: How professionals think in action."

As with Conant's (1957) two types of experiments mentioned in Chapter one, Schön also identifies two types of experiments: experiments in practice and experiments in research. However, Schön's notion of experiments in practice expands on Conant's (1957) "everyday" experiment. In research, Schön writes that experimenters are expected to adhere to norms of control, objectivity, and distance. He also adds that the main purpose in research is to understand a situation. However

> under conditions of everyday professional practice the norms of controlled experiment are achievable only in a very limited way. The practitioner is usually unable to shield his experiments from the effects of confounding changes in the environment. The practice situation often changes rapidly, and may change out from under the experiment. Variables are often locked into one another, so that the inquirer cannot separate them. The practice situation is often uncertain, in the sense that one doesn't know what the variables are. And the act of experimenting is often risky (Schön, 1983, p. 144).

Thus in professional practice, the practitioner is primarily interested in changing the situation from what it is to something he or she prefers. For example, a teacher tries 'time-out' as a form of discipline on an unruly student. According to Schön there are three types of experiment in practice: exploratory, move-testing, and hypothesis testing. They are summarized in table 2.

Table 2. Schön's experiments in practice

Experiment:	Description:
Exploratory	When action is undertaken to see what follows without accompanying predictions or expectations.
Move-testing	Any deliberate action undertaken with a goal in mind. "Do you like what you get from the action, taking its consequence as a whole?"
Hypothesis testing	Experimenter conducts a competition among hypotheses.

Summary

"The whole of science is nothing more than a refinement of everyday thinking" (Einstein, 1950, p. 17). The above is a fitting description of the conceptions of experimentation. The universal notion of experiment is to test one's idea or action. That general idea can be extended by varying the setting, purpose of the experiment, and assumptions made by the experimenter about the nature of science. This adds support for the view that there is no one method of science. Table 3 summarizes this literature review on conceptions of experimentation.

Table 3. Summary of the literature's conceptions of an experiment

	Everyday sense	Experiments in practice	Scientific sense (experiments in research)
Main Purpose:	• To try	• To change a situation	• To understand a situation

Types of Experiments:	• test or trial	• Exploratory
		• Move-testing
		• Hypothesis testing
			• Thought experiments
			• Contrived (controlled) interventions
			  • Inductive
			  • Deductive
			  • Critical
			  • Demonstrative

III. Related research studies on students' conceptions of experimentation

Although this study focuses on students' conceptions of experimentation, the relevant studies reviewed here are broader. This is because some of the research conducted under the headings of the nature of science and the epistemology of science also discusses experimentation. A review of the literature shows that there are three general approaches to the study of students' conceptions of experimentation:

1. Formal instruction: assess, teach, and assess again students about the nature of scientific inquiry,
2. Problem solving: ask students to solve a problem and document and analyse their action and thinking, and
3. Structured interviews: interview students about their thoughts on experimentation.

Formal instruction

Carey et al. (1989) developed and studied the effects of a constructivist view of scientific inquiry unit on 76 Grade 7 science students. The students' classroom teachers taught the aspects of scientific investigations and the rationales behind them to the students. The researchers extracted four levels of responses to questions on the nature or purpose of an experiment . Table 4 summarizes the four levels.

Table 4. The four levels of responses to the nature or purpose of an experiment.

Level:	Description:	Typical student response:
0	An experiment is described as a disembodied process unguided by an idea, question, or implicit assumption.	An experiment is "when you try something new."
1	There is no clear distinction between experiments and ideas.	To experiment is to try "something to see if it works" or "reacts."
2	There is a clear distinction between experiments and ideas.	To experiment is "to test to see if their [scientists'] idea is right."
3	The relationship between results and the idea being tested is clearly articulated.	[Carey et al. did not provide any examples.]

Although the researchers found some improvements between pre- and post interview mean scores, they expressed some doubts about their findings: "The interview required only that the student repeat points exactly made by the teacher several times during the unit" (p. 526).

Solomon et al. (1994) conducted a year-long study on how pupils' views of the nature of science changed when some of their learning materials were historically situated. The researchers sampled five classes of 11 - 14 year old pupils and identified seven images of scientists at the start of the study. Each of the seven images of scientists had an associated character and epistemology. For example, Solomon et al. argued: "Believing that scientists would not know what they expect to happen when they carry out experiments is clearly one aspect of the cartoon view" (p. 363). The other characters and epistemologies were: vivisectionist (there is no expectation of experimental outcome), authoritative (experiments yield correct results or knowledge), technologist (experimental outcomes are useful artifacts), teacher (experiments are often repeated), pupil (experiments do not work), and entrepreneur (there is competition and secrecy in experiments). Another finding that had relevance to this study was the pupils' reasons for why scientists do experiments. The three reasons given were: discoveries, explanations, and making helpful things.

The above studies indicate that students have a commonsense notion of the role of experiments. In that notion there is a lack of emphasis on theory and evidence (which are constituents of scientific thinking) and a focus on the results of an experiment. In an attempt to provide a more meaningful context for the students to respond, research has also been completed on the knowledge students bring to experimental activities and how this knowledge affects their procedure, observation, and interpretation of an experiment.

Problem solving

Meyer (1991) conducted a study to examine pairs of Grade four and pairs of Grade seven students' actions and knowledge used while designing and conducting experiments to determine the strength of various magnets. When the students were probed about their beliefs and knowledge about experimenting, they said that an experiment means: "to find out," "to try something out," or "to prove something" (p. 61). The above comments matched Carey et al.'s level 0, 1, and 2, respectively.

Schauble et al. (1991) investigated 16 fifth- and sixth-graders' problem solving methods in order to elicit different task definitions of experimentation. The students' experimentation approaches were categorized as either the engineering (practical) model or the science model. The goal of the engineering model of experimentation was to make a desired or interesting outcome occur or reoccur. The goal of the science model of experimentation was to understand relations among causes and effects. The researchers reported significant improvements in inferences about variables for the students who began with the engineering problem and then went on to the science problem. The results agreed with their hypothesis that children use the more familiar engineering model of experimentation approach in science experiments.

Structured interviews

Larochelle and Désautels (1991) interviewed 25 students between 15 to 18 years old who were finishing high school. The principle research question was: "What is scientific knowledge" (p. 380)? "... with a few exceptions, the ideas of tinkering, empirical inventory and craft production were the main features of the subjects' representation of the nature of scientific experimentation" (Larochelle and Désautels, 1991, p. 384). The relationship between scientific knowledge and experimentation was absent from the students' thoughts. The researchers raised the need for further research to explore ways to help students and teachers "integrate into their own thinking the reflective, conflictual and unfinished character of any production of knowledge" (p. 387).

Thompson (1990) explored the range and prevalence of misconceptions about science process skills by interviewing 32 Grade 7 to 10 students who had an interest in or just completed a science fair. The participants were divided into four groups: "science fair winners," "science fair non-winners," "science fair participants," and "science fair non-participants." Thompson reported that all four groups had an inadequate understanding about the processes of science (planning experiments, hypothesizing, identifying and controlling variables, inferring, observing, interpreting data and predicting). He suggested the confusion between the commonsense meanings and scientific meanings of the words like "independent," "dependent," and "control" as the reason for the students' misconceptions.

IV. Summary

This chapter has presented theoretical considerations and empirical studies relating to students' science conceptions, in particular, experimentation. A parallel can be drawn between the above research findings and the literature's conceptions of an experiment. Students have a commonsense notion of experiment through their everyday experiences. When the need arises to implement the scientific sense (to understand a situation), students could proceed no further than the practice sense of the word experiment. There is a need to study further students' conception of experimentation.

This study differs from the other studies in three ways:

1. The students are interviewed not once but three times (at the start, near the middle, and at the end of their science fair). This provides a more complete picture of their conceptions.
2. The use of a journal required the students to record their thoughts for later reflection.
3. The teacher-research role allowed for a better ability to describe events that are pertinent to the study.

The next chapter discusses the methodological aspects, context, and students of this study.

CHAPTER 3

Methodology and Analysis

"The best stories are those which stir people's minds, hearts, and souls and by so doing give them new insights into themselves, their problems and their human condition. The challenge is to develop a human science that can more fully serve this aim. The question then, is not "Is story telling science?" but "Can science learn to tell good stories?" (Reason, cited in Seidman, 1991, p. 3).

I. Introduction

In this chapter, I will detail the classroom context surrounding the researcher and the students. The purpose is, again, to enable the reader to have a clearer understanding of the study. By describing the context of the study fully, the reader will also be better able to determine the degree this study's findings might have in his or her area of interest. The rest of the chapter will focus on the research methods and data analysis procedures.

The focus of this year long exploratory study was on describing and interpreting four Science 9/10 honour students' conceptions of experimentation during a science fair. As a teacher-researcher in this study, I had at least two 'hats' to wear. As a teacher, I had to make certain that "the teacher's primary job is to teach, and any research method should not interfere with or disrupt the teaching commitment" (Hopkins, 1993, p. 57). As a researcher, I had to select research methods that were thorough and robust enough to enable me to systematically and critically scrutinize the data and make valid interpretations. Other issues such as the power relationship between myself and the students and the students' ability to commit to the length of this study were also taken into consideration in the selection of the research methods. With the above criteria in mind, I selected the students' science fair journals, questionnaires, and the phenomenological in-depth interviewing technique (Seidman, 1991) as the most appropriate data collection tools for this study.

II. Setting and participants

The school

The participants were selected from a high school set in an urban city in the Lower Mainland of British Columbia. With a student population of approximately 2100, the school offered a comprehensive range of academic and non-academic courses including 'accelerated' (honours) and remedial (modified) courses in the junior sciences and Advance Placement (A.P.) courses in the senior sciences. For example Science 8 students with a year-end average of less than 50% and the teacher's recommendation could take the modified Science 9 course in the following year. Science 8 students with a year-end average of 80% or higher and the teacher's recommendation could take the Science 9/10 Honours (Sc 9/10H) course in the following year. Upon successful completion (73% or higher) in the Sc 9/10H course, the student could enter any Grade 11 science course including A.P. courses. The University of British Columbia, for example, recognizes A.P. courses and these courses are eligible for transfer credit or advanced placement.

The primary purpose of the Sc 9/10H course is to provide an avenue for the more capable students to complete the Science 9 and Science 10 curricula in one year so that they can advance to the senior sciences sooner than if they had to take the regular courses separately. Since there is no ministry curriculum for the Sc 9/10H course, the curriculum that is taught evolved from an amalgamation of selected major science strands (biology, chemistry, and physics) and topics from the Science 9 and Science 10 curricula. All the students in the Sc 9/10H course are required to complete, outside of class time, a science fair project either by their self or with a partner. The science fair is worth between 15 and 20 percent of a student's grade in each of the school's three terms. The purposes of the science fair are to engage the students in a scientific investigation of a question chosen by the students, to showcase their achievements, and to select the 'top' projects from the science fair for entry to the Greater Vancouver Regional Science Fair. The next level beyond the regional science fair is the Canada-Wide Science Fair sponsored by the Youth Science Foundation Canada.

Two Sc 9/10H classes were offered in the 1994-95 school year. The school's time-tabling schedule was such that I taught one of the two Sc 9/10H classes and another teacher (a science department head new to the school that year) taught the other. The school also had mid-year grade-wide common examinations in selected courses. These exams dictated that a common content be taught to the students. The Sc 9/10H course had such a grade-wide exam.

From September 1994 to the mid-year exam in January 1995, the chemistry units in the Science Probe 9 (first edition) and Science Probe 10 (second edition) textbooks provided much of the structure, content, and lab activities for the course. During that time, the Sc 9/10H students also worked on their science fair projects on their own time in addition to their classroom work. Neither the other teacher nor myself provided specific lessons on how to conduct science fair projects. However, the students were given science fair reference materials (science fair bibliographies, project grading format and procedure, and time-line for completion), encouraged to ask for help from resource people such as librarians, teachers, and scientists, and received regular (about once every three weeks) feedback through their science fair journals. From time to time, I answered questions from the students about the science fair during class time. Throughout the science fair, the other Sc 9/10 H teacher, the Grade 9 counsellor, and myself acted as resource people and organizers of the science fair.

Selection of the student participants

In August 1994, I submitted a request for and later received permission to conduct my study from the UBC Behavioural Sciences Screening Committee and from my school board. In September I presented both Sc 9/10H classes (14 year-olds) with the background, rationale, and request for volunteers for the study. The student and parent consent forms returned slowly over a three week period. Twenty nine out of 31 students from my class and 21 out of 31 students from the other Sc 9/10 H class returned the consent forms. Many students from both classes wanted to know if additional marks would be given to the volunteers. The answer was "No" and research ethics were discussed briefly with the students. After the first visit to the other Sc 9/10 H class, two male students in that class indicated that they would volunteer. However, for reasons not pursued, they declined to participate when I went to confirm their participation and answer questions about the study at the second visit. Since I did not wish to intrude any further on the other class' time and to better monitor how the teacher's actions would affect the results in this study, I decided to seek volunteers only from my class.

Initially, four male students (two with and two without experience in a science fair) from my class volunteered to be a participant in the study. In order to provide a more balanced look at the research questions, it was decided in consultation with my thesis committee to make an additional request for female volunteers. As part of my Sc 9/10H course to find out more background information about my students, I gave out the students' conceptions of experimentation questionnaire (see Appendix B) to all my students at the beginning of the year. Based on the students' responses to Part A of the questionnaire, I separated the questionnaires into four groups: female students who participated in a science fair, female students who never participated in a science fair, male students who participated in a science fair, and male students who never participated in a science fair.

From the two male groups, I cross-referenced them to those students who volunteered to be a part of this study and randomly selected one male who participated and one male who had never participated in a science fair. As for the female volunteers, I approached one female student in each response group at a time and asked her if she had any questions about the nature and the requirements of the study. I fully understood the teacher-student power relationship that I had. I only asked the students I approached to reconsider volunteering. Thus I was sensitive to and respected a student's wish to decline to volunteer. By early November 1994, all four students necessary for this study were gathered.[5]

[5] Even though the selection of the participants was completed in early November, the first set of interviews began as soon as the two male students were chosen. This was done because capturing the students' conceptions of experimentation at the start of the year was a purpose of the study.

III. Sources of data

In order to document, as detailed as possible, the experiences and conceptions of experimentation of the participants and collect reliable and valid data within the constraints and context of this study, data from several sources were collected. The use of multiple sources (science fair journals, questionnaires, multiple audio taped interviews, and science fair reports) provided a means for triangulation, a method critical for interval validity and establishing trustworthiness (Lincoln & Guba, 1985). Also, resource books on science fairs, verbal anecdotes from my colleagues, and personal experience made me aware of the fact that sometimes outside assistance overshadowed a student's own efforts in a science fair project. Thus the use of the questionnaire and audio taped semi-structured interviews served as an additional check on the consistency of the experimentation described in the students' journals. It should be emphasized that with the exception of the audio taped interviews, every form of data collected (students' conceptions of experimentation questionnaires, student journals, and science fair report) was also completed by the other students as a regular part of my Sc 9/10 H course. Thus the only commitment, outside of the course requirements, for the participants in this study was the three audio taped interviews.

IV. Overview of the data collection procedure and timeline

My experience with the Sc 9/10 H course in the previous school year showed that the students would be preoccupied with much of the course requirements (course work, mid-year exams, and science fair) throughout September to March. Thus, as mentioned earlier, the data collection procedure was designed so that much of the data (questionnaires and student journals) came from a regular part of the course work. The audio taped interviews were the only part of the study that was conducted outside of regular class time. Originally, the first set of interviews was scheduled for the start of the year, the second was set at the time when students were most occupied with the science fair (middle of February), and the last was set for immediately after the science fair. However, time conflicts with personal commitments, school functions and holidays, and the selection of one of the study's participants to the regional science fair, changed the interview dates slightly. This modification was not considered to have adverse effects on the results of the study because of the multiple sources of data. Figure 1 summarizes the major activities in the study and the approximate times they took place. The figure also previews the discussion on the data collection instruments that follows.

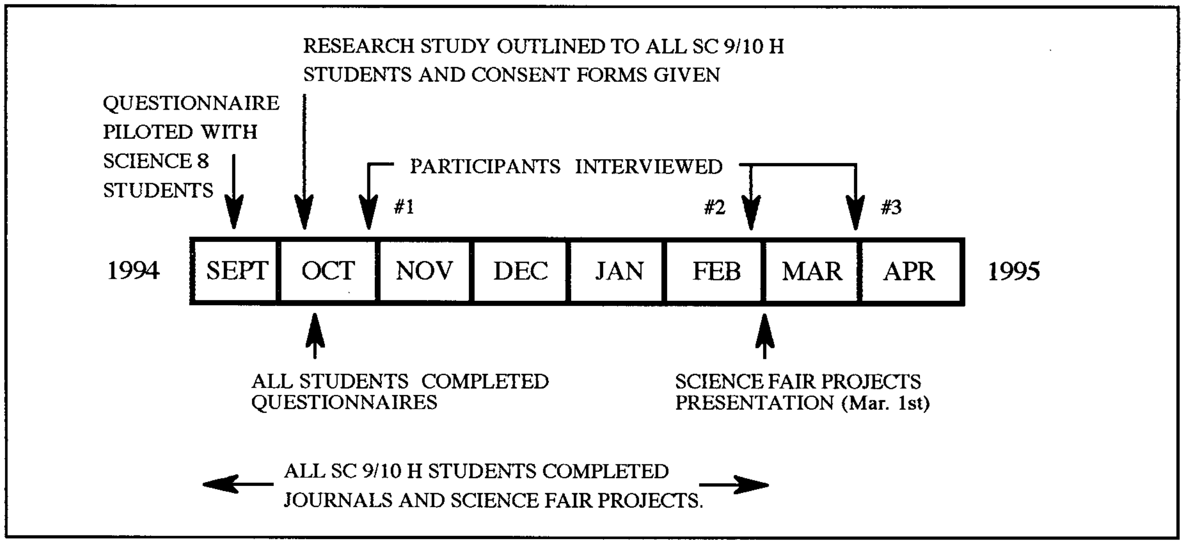

Figure 1. Timeline showing the major activities in the study and approximately when they took place.

V. Instruments

Conceptions of experimentation questionnaire[6]

Since the participants would not have had sufficient time to write or reflect on their science fair projects by the first interview, the purposes of the questionnaire were: to serve as a starting point for discussion and a tool for the students to reflect on their conceptions of experimentation in subsequent interviews. Since I could not find such a research inventory for these purposes, one had to be created. Therefore, claims could not be made for the thoroughness of the questionnaire to cover all aspects of conceptions of experimentation. Also, claims for the reliability and the validity of the questionnaire could not be made because it was not sufficiently evaluated.

However, the questionnaire was not hastily written. There were four components in the questionnaire (see Appendix A): Part A - background questions on students' prior science experience in formal and informal settings, Part B - attitudes about experimentation in and outside of science class (using semantic differential-type items), Part C - meaning of experimentation by ranking four examples of experimentation, and Part D - planning a scientific investigation (Do plants like music?). Parts A and B were adapted from the 1991 B.C. Assessment of Science. Pact C was my attempt at designing a way for students to clarify their meaning of experimentation by explaining their ranking of four examples of experimentation. The four examples followed Medawar's (1969) four types of experimentation. Part C was the only part of the questionnaire that was completed by the interviewees at each of the interviews to help the students reflect on their conceptions of experimentation. Part D was adapted from a study, similar to this one, that I did for a graduate course.

[6] This questionnaire was developed initially for the sole use of this study. However, upon the recommendation of my thesis committee members to the questionnaire's practical classroom use (to learn more about all the students' background in experimentation), the questionnaire was also given to all the students in my Sc 9/10 H class.

This questionnaire was piloted, in September 1994, on my Science 8 students to check for ambiguity and misunderstanding in the wording and directions. I assumed that if Science 8 students understood the purpose of and directions on the questionnaire, then the Sc 9/10 H students would likewise have little or no difficulty in completing the questionnaire. I made minor adjustments to the wording as a result of the pilot. I also learned more about my Science 8 students as a result of the pilot.

Science fair journals

As stated earlier, one of the purposes of the science fair was to give the Sc 9/10 H students an opportunity to perform an open-ended investigation of their own choice. However, with no specific lessons on completing a science fair given by the teachers and a need to monitor and provide continuous feedback to the students, each student had to maintain a science fair journal to record, as detailed as possible, every step of their investigation. The journals also provided a means for the students to reflect on their progress. The journals were collected about once every two to three weeks and the students were given marks for completing them. Two hand-outs with suggestions on what to write down in the journals, with an emphasis on thinking about how science generates knowledge, were given at the start of the school year (see Appendix B).

In-depth phenomenological interviews

As pointed out in the introduction of Chapter 1, this study was about the lived experiences of four students' experimentation during a science fair. The selected interviewing technique must somehow tap into these experiences. Given the extended duration of the study, the small number of participants, and the nature of the research questions, I had to search for an interviewing technique that would satisfy the above context and capture, as fully as possible, the students' conceptions of experimentation. The interview schedule selected was

Seidman's (1991) model of in-depth phenomenological interviewing. According to Seidman (1991):

> In this approach interviewers use, primarily, open-ended questions. Their major task is to build upon and explore their participants' responses to those questions. The goal is to have the participant reconstruct his or her experience within the topic under study (p. 9).

There were three semi-structured interviews (see Appendix C) spread over the school year: October 1994, February 1995, and March/April 1995. These times roughly corresponded to the beginning, midpoint, and end of the students' involvement in the science fair. The first interview focused on the students' prior experience in, and conceptions of, experimentation. The second interview focused on the details of students' experience on research and experimentation during the science fair. The final interview focused on students' reflection on their meaning of experimentation.

Since each interview had a specific function, the types of questions asked had to match that function. In addition, questions derived from the students' journals and/or questionnaires were also asked for clarification and understanding of the students' experimentation. These multiple interviews tended to be more accurate than single interviews because they would enable the interviewer to get corrective feedback on previously obtained information (Reinharz & Davidman, 1992).

After completing the first set of interviews, I thought about my interactions with the participants during the interviews. Although the participants said they were 'okay' with being interviewed, the female participants especially, gave very short responses. Perhaps this was due to a combination of my lack of interviewing experience, to their uneasiness with being interviewed, or being interviewed by their teacher. A change was made to the interviewing protocol to try to elicit fuller responses. For the second and third set of interviews, some of the interview questions were given to the participants a week prior to the actual interview. Therefore, instead of having a couple of minutes to think about the questions, the participants had a longer period of time to think about them so that more time could be devoted to discussion in the interviews. Although not all the students wrote down their responses to the interview questions, the change seemed to have made a greater difference with the female students than with the male students. The female students gave longer and fuller responses. However, the change could have also been due to greater familiarity with the interviewing process.

VI. Analysis of Data

The limited number of participants and the unique experiences that each of them encountered throughout this qualitative study made it most suited for an interpretational analysis. Of the four types of interpretational analysis: descriptive narration, topology, theme analysis, and grounded theory, theme analysis seemed most appropriate for this study. The role of theme analysis was to "describe the specific and distinctive recurring qualities, characteristics, subjects of discourse, or concerns expressed " (McMillan & Schumacher, 1993, p. 508). What follows is the procedure I took in transforming the data to facilitate the analysis.

Data from the questionnaires

The purpose of the questionnaire was to generate questions, relevant to the study, to ask at the first interview and to act as a tool for reflections at subsequent interviews. Part C - "What do you mean by experimentation?" was the only section of the questionnaire that the participants had to fill out, again, at the second and third interviews. Part C acted as a probe to try to elicit differences, if any, in the students' conceptions of experimentation. Other than the audio taped interview records of the responses, no specific data were reported from the questionnaires.

Data from the science fair journals

The data from the journals were used to help answer the research question: "What does experimentation mean to the students?" Thus instances and references to experimentation along with the context that surrounded them were extracted from the journals and recorded. These records were used in building the story of each participants' sense of experimentation throughout this study. The records were also compared with the interview notes to determine whether or not the students' conceptions of experimentation were consistent.

Data transformations

The data from each interview went through several transformations. First, the audio tapes were transcribed verbatim. Then the transcripts were examined for references to each of the research questions. A label (e.g., 'm' for meaning) was placed next to each reference on a copy of the transcripts. Then I used my word processor to set-up three columns (one for each interview) and three rows (one for each research question). I then typed in each reference, along with the page number of where the reference came from, within the appropriate box. For example, a reference to research question 'm' at the first interview would be placed in the first column, first row. Typing the references into the grid enabled me to think about the appropriateness of my categorizations while I typed them in. Another advantage of this set-up was the ease with which I could 'cut and paste' themes. If one theme seemed to fit better within a different 'box,' it was much easier to move it around with the word processor. The three column format also provided a means to compare and contrast the three interviews when printed out side-by-side. All the records (journals, interviews, and questionnaires) served to support the research questions. The records also act as a method of triangulation to determine if each student's responses at each interview is consistent with the records.

VII. Validity and Reliability of Methodology

In any research, the results will not be credible if validity and reliability concerns are not addressed. In qualitative research internal validity refers to the degree to which the researcher and the participants agree on the findings. Some of the strategies that I used to increase the internal validity were: closely matching the participants' language, collecting evidence in natural settings, and researcher self-monitoring of all phases of the interview process.

External validity refers to how well others will understand similar studies through the extension of the understandings of a particular study. Two threats to external validity are comparability (how well the study is described) and translatability (the thorough and appropriate use of theoretical frameworks and research strategies). The threats to external validity were minimized through detailed descriptions of every aspect of the study.

Internal reliability in qualitative research is the consistency of the researcher's interactive style, data recording, data analysis, and interpretation of participant meanings from the data. Threats to internal reliability of interviews were reduced through verbatim accounts (transcripts), low-inference descriptors, audio taped recorded data, and triangulation.

External reliability refers to the consistency of the study's design. The following six aspects were made explicit in this study to maximize external reliability: researcher role, informant selection, social context, data collection and analyses strategies.

VIII. Summary

This chapter detailed the context surrounding this study, the four participants and their selection process, the sources of data and how and why they were collected, the analytical framework, and addressed the validity and reliability of this study. The data collection consisted of three periods: at the beginning, near the middle of, and after the science fair. The interviews acted as a thread that tied the questionnaires and the journals together and as the main resource for triangulation. The next chapter will discuss the results of the data analysis.

CHAPTER 4

Results

"Teaching, even the best teaching, can only organize information and experience in a manner that permits or facilitates the graspings of meaning by the learner" (Novak, 1990, p.64).

I. Introduction

This chapter presents data which address the research questions. The data sources are the participants' science fair journals, questionnaires, and interviews. Since this study consists of four individuals with different prior science fair experiences who completed different projects, the results are presented as a case on each of the participants. All four cases have a common structure: introduction, conceptions of experimentation, structured lab activities, demonstrations, and summary. Each case also includes a summary table of the key conceptions of experimentation. The summary table allows the reader to review the conceptions of experimentation all at once.

The story on each participant begins with a brief description of the student's prior experiences in science and the science fair project completed. Supportive data are then used to address the research questions in sequence. Lastly, each case concludes with a summary that highlights the salient points.

II. The Case of Jennifer

Introduction

In terms of past experiences in experimentation, Jennifer indicated on her questionnaire that she had visited a science centre in Grade five and participated in classroom science activities. Jennifer had no prior experience in a science fair. For their science fair project, Jennifer and her partner (a male student from the other Sc 9/10 H class and a non-participant in this study) decided to show how solar energy could be used to heat a model house using a roof-top solar energy collector and an in-floor radiant heating system. On January 7, Jennifer drew the following diagram (Figure 2) for her model.

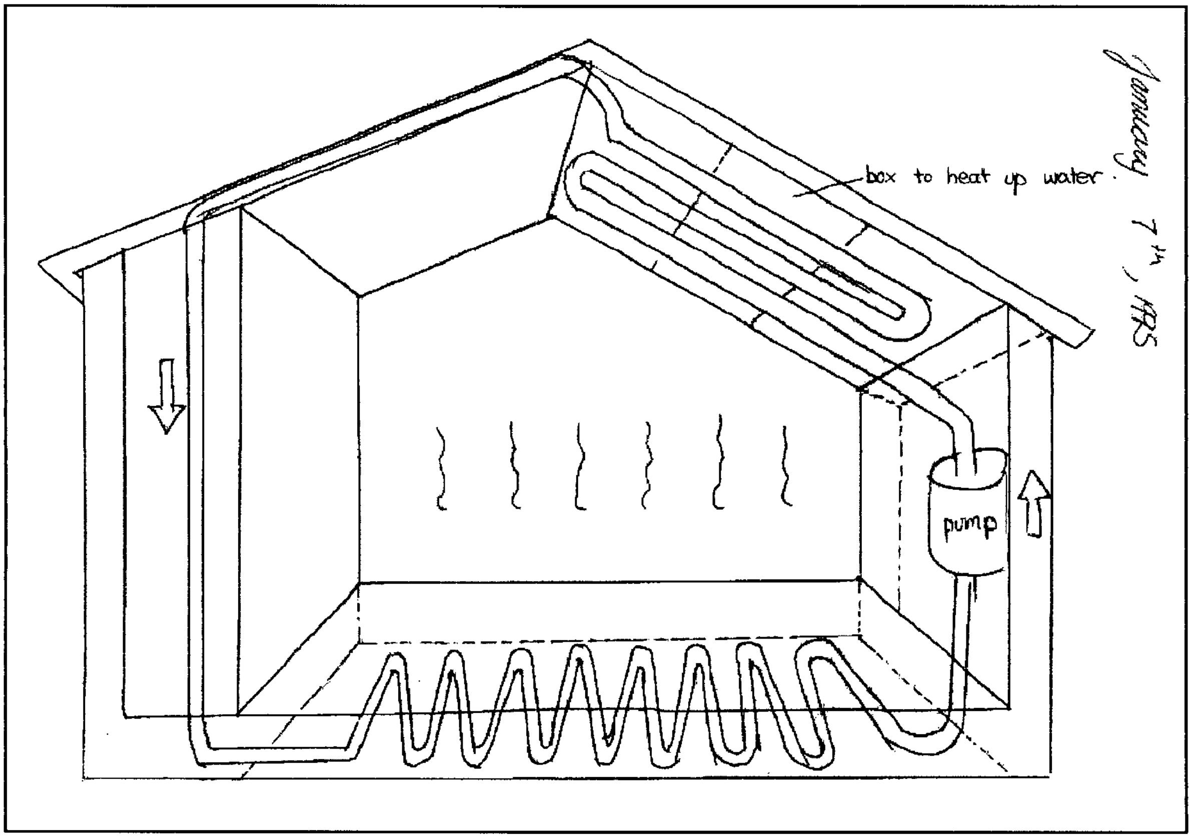

Figure 2. Jennifer's solar energy heating project diagram.

In her October 20 journal entry, Jennifer wrote about the original concept of her solar energy project (which was not about heating) and questions about how to build the model:

> I took [industrial education] last year and I really like the drafting and electronic parts of the course. Maybe I can apply both things together in my project. I was thinking of making a model of a house. I can also make a floor plan for it. Then I'll make some furniture to go with it. The electronic part of it will be the lights or may be the heating system in the house. I know this is going to be very hard to do. These are the problems I can think of for now.
> - how big is a solar cell? ([Is it] small enough for the model?)
> - how does the circuit go?
> - how do I connect all the things in the model?
> - how big should the model be?
> - is it possible to make [the model]?
> - where can I get information?
> - who can I ask if I had problems?
> - will this topic be allowed in science fair?
> - how should I design the house?

An analysis of the interviews showed that developing the procedure for building her model was an important part of Jennifer's conceptions of experimentation.

Conceptions of experimentation

During the interviews, especially the first interview, Jennifer gave very short responses to my questions. Perhaps this was due to our initial apprehension in the interview setting. However as explained in Chapter 3, a change was made to make the interview less like a question and answer session and more like a conversation. Later interviews with Jennifer resulted in lengthier responses.

At the first interview on November 1, Jennifer described an experiment as a science activity where she could develop the procedure and try it herself. In fact one of her most memorable science activities was one she thought up herself:

> Jennifer: When I was in Grade 7 we had to make an experiment. The purpose of it [was] to test if ... I can't remember the purpose. Let me think. It's to test if there's acid in Coke or not ... And compare the different acids in [soda pop]. Like say have different kinds of pop: 7-up and Coke and Sprite and all that. That's the one I really like.

Wayne: Was it one that you thought [up] or was it one that someone else told you to do?

Jennifer: I made it up.

As Jennifer built her model, she recorded one of her first practical experiences in her journal. On February 11, she wrote: "Now I'm finished with the base [of the box for] my model. It was my first time at hammering something together. At first, it was hard for me to hammer the nail in straight. But after practicing a couple of times, I got better." Later in the same journal entry, she wrote about stabilizing the model's roof:

> Today I finished the framework of the house. I tried so hard to figure out how to build the roof and make it stable. But finally, I got it. Should I paint it? It looks quite good now.

Jennifer's efforts at making a stable roof and her sense of accomplishment and self-discovery added to her conceptions of experimentation.

At the second interview on February 21, Jennifer added "a process of learning" to her conception of an experiment:

Wayne: To you, right now, what does it mean to experiment?

Jennifer: Well, an experiment to me now is like ... It's just a process of learning. And I think it's just a process of learning. Any kind of learning.

Wayne: Which part or parts of your project is most like what you mean by an experiment right now?

Jennifer: Actually everything. But ... I think it's actually putting the stuff together - the planning part.

Wayne: What exactly about the planning that is most like what you mean by an experiment?

Jennifer: You have to put all the information together in order to give a result.

Wayne: And that's an experiment?

Jennifer: To me it is. Actually putting it together.

Wayne: Can you give me an example of your project that shows this?

Jennifer: Well I'm building a model so you have to plan where to put this and where to put that. The planning is really important. That's [what] I feel is what I mean by an experiment.

Wayne: I'm still not very clear what planning you're doing in your project that is like what you mean by an experiment.

Jennifer: Well, like planning right, you have to get all the information together. And then sort them out and put it into something that would [represent] what you want to say.

Wayne: Can you use your project as an example of what part of your project is planning.

Jennifer: Well, I have to plan what the structure of the model is. And then I have to apply the theory to it to make it work.

Wayne: And that's an experiment?

Jennifer: Ah hum.

There were several components to Jennifer's notion of a "process of learning:" reading, understanding what was read, and thinking, planning, and carrying out the procedure. The important parts of an experiment were: thinking and planning. Thinking and planning involved researching for relevant information, sorting through the information, transforming the information to include some personal input, and presenting the information:

At the end of the second interview, Jennifer reiterated some of her components of an experiment:

Wayne: So can we just summarize again. An experiment to you is where you have to read something ...

Jennifer: Or get information. Absorb it, understanding it, put some thoughts into it, to comment [on] it or to make something out of it. To create something.

Wayne: So if you have all of that, then you would say that's an experiment.

Jennifer: Ah hum.

Wayne: If you don't have one of those or two of those?

Jennifer: You can say it's just a part of an experiment but not an experiment.

By the third interview on April 5, Jennifer added "reflection" as another component to her "process of learning:"

Wayne: So right now you think an experiment is something you ...

Jennifer: A process of learning.

Wayne: A process of learning.

Jennifer: Ah hum.

Wayne: And what's in the process?

Jennifer: Everything. Like the whole process. Like planning, reading, copying, absorbing the information and the reflections.

Wayne: Reflections.

Jennifer: Ah hum. Like you have to reflect on what others [have] said. So it makes you think.

Wayne: Who are the others?

Jennifer: Oh, you know the books, teachers, and other people [such as the judges].

Jennifer summarized the rationale for her conceptions of experimentation by saying that: "There's no ideal experiment. I mean like it's a process of learning. It depends [on] what's important to you and what's not. So [the concept of an experiment] depends on the person."

Structured lab activities

In the first interview Jennifer did not consider structured lab activities as experiments because the students were "copying" someone else's procedure. There would be no thought put into the procedure by the students and the students would be merely observers in the activities. However, in the second interview, she changed her view. As long as an activity involved a "process of learning" then it was considered an experiment:

Wayne: What about the activities that we have done in the class. Are they experiments?

Jennifer: Oh you mean the biology things [learning the parts and functions of a microscope and learning how to prepare glass slides]?

Wayne: Could be the biology, could be the chemistry ... the activities that we did in the classroom. Are they experiments to you?

Jennifer: Ah hum. Yes they are.

Wayne: How are they experiments to you?

Jennifer: Like cause it's a process of learning and like you get the information and you have to digest it. You can't just like read everything and understand it right. You have to really think and then understand it. So I think it is.

Again in her third interview, Jennifer reaffirmed that textbook structured activities were experiments because the activity's questions required her to think about the activity:

Wayne: So textbook activities, to you right now, they are experiments.

Jennifer: Yes.

Wayne: Because ...

Jennifer: It's a process of learning and it involves thinking and it involves the reflections.

Wayne: Do all the activities make you think and reflect?

Jennifer: Yah cause you have to learn. You have to absorb the information and think [about] how it works and why it works and stuff like that and you have to answer the questions. So it makes you think again. If you reflect on it then it shows that you really think it. You really thinking and you have to comment on it. May be you don't agree with what happened and or just thought about it.

Demonstrations

In the first interview, Jennifer thought that a demonstration was not an experiment because there would be no "new" thoughts put into it by the person performing the demonstration:

Wayne: Okay. How about when I showed something in class. Like when I put the sodium and potassium in water and I showed it to the class. Do you remember that one?

Jennifer: Ah hum.

Wayne: Now was that an experiment to you?

Jennifer: Well to me it's not. It's just demonstrating.

Wayne: Suppose I asked you: 'Jennifer can you come up to the front, cut a piece of sodium off and then put it in water.'

Jennifer: That ... It's not [an experiment] because I didn't think of the experiment. Someone else did.

Wayne: So if you thought of it yourself then it would be an experiment?

Jennifer: Ah hum.

A similar notion about demonstrations continued in the second interview. However, she was beginning to show an uncertainty in her conviction.

Wayne: So a demonstration is not an experiment.

Jennifer: If you planned it yourself and you demonstrated it then it is. But if you copied it then it's not.

Wayne: What do you mean by copied it?

Jennifer: Do it from ... copy the whole thing using [other] people's ideas.

Wayne: Are the ones that we've done in the classroom like that?

Jennifer: In a way they are. Yes they are.

Wayne: And they are still experiments to you?

Jennifer: Um ... I'm not sure.

Wayne: Not sure. What are you not sure about?

Jennifer: Because like I said the process of learning ... but ... the ideas overlap so I can't decide.

Wayne: Which ideas overlap?

Jennifer: Like ... I said that an experiment means a process of learning. But you have to copy something in order to learn right. So I'm not sure.

In the third interview, Jennifer's reverted back to her initial conception about demonstrations:

Jennifer: Well my definition of an experiment is a process of learning but it's also includes your own thinking. You don't just copy things out. It's not right. Well for [example Part C, example (b) of the questionnaire] says that a student saw someone explaining and demonstrating how to make a volcanic explosion using vinegar and baking soda right. The student just copied it. Repeated. Like the key word is repeat the procedure. That's not right.

Wayne: How did you know it was the key word?

Jennifer: Well in my definition of an experiment you don't repeat someone's work. You just pick the idea and then to modify it.

Summary

Table 5 provides an overview of the conceptions at each of the interviews for the case of Jennifer.

Table 5. Summary of results for the Case of Jennifer

Research Questions	Interview #1	Interview #2	Interview #3
Conceptions of experimentation	• Experimentation is a science related activity.	• Experimentation is a "process of learning." • Any kind of learning. • The individual is curious about the learning.	• Experimentation is a "process of learning." • There is input by the individual.
	• The procedure has to come from the individual and be carried out by the individual.	• Involves thinking of and planning out a procedure. • Involves 'creativity'	• Involves thinking of and planning out a procedure. • Involves 'creativity' • Involves 'reflecting' on the feedback of others.
Conceptions of structured laboratory activities as experiments	• They are not experiments because they are just "copies" of other's work. • They are mainly observations.	• They are experiments because they are part of the learning process. • They provide learning experiences. • They involve thinking and learning.	• They are experiments because the questions make the students think and reflect on the activity. • If the students were allowed to modify the procedure to achieve the same purpose then the activities were more of an experiment.
Conceptions of demonstrations as experiments	• They are not experiments because they are just "copies" of other's work.	• They are experiments because there could be thinking and learning by the individual.	• They are not experiments because there is no modification by the individual.

As the science fair progressed, Jennifer added more characteristics to her conceptions of experimentation: a personally developed procedure, a process of learning, and reflecting on one's learning. These features mirrored the main phases of Jennifer's science fair project.

Initially Jennifer was concerned about how to build her model. Even though she had seen similar ideas in her reference books, she did not believe it was 'right' to replicate them. She believed that an experiment must be 'original.' Thus she wanted to come up with her own design for the model.

As the science fair presentation drew near, she was assembling her model and collecting data. In the process Jennifer learned, among other things, how to hammer a nail properly and stabilized the roof of her model. These experiences were important to her conceptions of experimentation and they formed the bases of her conceptions of experimentation as well as her thoughts about laboratory activities and demonstrations.

III. The Case of Victor

Introduction

Victor began the school year with much anticipation about his science fair project. He participated in a Grade 7 science fair and heard of the Science 9/10 Honour science fair in Grade 8. He said he even thought about possible ideas to consider for the science fair in the summer prior to his Sc 9/10 H class. At the start of the 1994-95 school year, Victor and his partner (a male student from the same class as Victor and a non-participant in this study) discussed the science fair with their power mechanics teacher, and the teacher gave them a few suggestions on computerized engines to think about. While unsure of the final question to investigate for the science fair, Victor spent much of his time researching various sensors and their functions in a computerized car engine. For their science fair project Victor and his partner conducted a comparison on the effects of disconnecting various emission control devices and observing the emission of hydrocarbons (HC), carbon monoxide (CO), and carbon dioxide (CO_2) on three different makes and brands of vehicles.

Conceptions of experimentation

Learning was the major theme identified from the analysis of Victor's journal entries and interviews. If Victor learned something from an activity, then the activity was an experiment. Some of the activities Victor considered as experiments were: following a prescribed procedure, performing a demonstration, and learning how to in-line skate. Victor considered the above activities as experiments because he had a hands-on involvement in the experience. The learning theme was evident in the first interview on October 13:

Wayne: So an experiment to you is anything that you learn something from.

Victor: Yah, that's mostly ... as long as you learn something.

Wayne: And the more that you are involved, then it's more an experiment?

Victor: Yah, it's more interesting because you know you're actually causing things like ... if you get to use a Bunsen burner you know ... Even though nothing may happen you know you're trying. You did your best in seeing if there can be more of a reaction or speed up the reaction or slow it down. As long as you get to do most of the things. Not seeing someone on TV do it. You know you didn't do anything. You just learn what happened. It's not [an experiment].

Wayne: So, [watching a demonstration] is not an experiment.

Victor: Well, it's still is an experiment to them of course. It's considered an experiment but then until you get to do it yourself I don't consider it an experiment until I get to do it myself.

Later on December 4, in response to my query if Victor's project was an experiment, he responded in his journal:

> ... I was thinking about your question: "Is this [project] an experiment?" Well yes it is. [My partner] and I have planned to have a section in our project focus on the future outlook of the computerized car. The question is: "Can a car have maximum performance, zero emission, and low fuel consumption?" An experiment to me doesn't always mean things to do with chemicals or plants but to do with anything that you can change or create and learn from.

After five months of research on the names and functions of the various emission components in a computerized car engine, Victor wrote, on February 4, about the 'experiment' he and his partner conducted at a garage two week earlier. It was also in this entry that a clearer conception of what Victor meant by experiment was revealed. The purposes of their 'experiment' were:

> To observe the difference between emissions of a computerized car and those without computers and to observe if a computerized engine can maintain functioning upon the removal of certain parts - in this experiment a vacuum hose and a MAP [a sensitive vacuum gauge] sensor.

The procedure they followed was essentially to disconnect a sensor and record the resulting emission on a monitor. The conception of experimentation I gathered from the above purposes and procedure was the everyday sense of experimentation. Victor was testing what would happen if he took a particular step. However, there were no intention in changing the situation as in experiments in practice (for example to try to reduce emission) or to understand the situation as in scientific experimentation (for example to understand how the emission device reduced emission).

The idea of an experiment as a hands-on learning experience was repeated in the second interview on February 24:

> Wayne: Now at this very moment or at this stage of your science fair project, what does it mean to experiment?
>
> Victor: To me by experiment means anything that we can learn from. Anything that deals with science and basically whatever. [The] basic thing is whatever you can learn from is what an experiment means to me.
>
> Wayne: What is the most interesting experience of your science fair project so far?
>
> Victor: [The] most interesting experience for me is being able to actually ... hands on ... reading off a [print-out], [actually] seeing the inside a car, dismantling the sensors. Well we had gone down to [the garage], that was probably the biggest experience I had for [the] project because over there we were allowed to [physically] take out the sensors and [saw] what occurred on the computer at that point in time and what occurred to the engine at that point in time. It's not like ... Air Care[7] [where] you put your car in and you get a paper which tells you what happened [in] your car and everything. We were there and we observed what occurred and ... what the ... readings were and ... we could see what effects sensors and hoses and all the other things have.
>
> Wayne: So you liked that part of the project.
>
> Victor: That was basically where we learned quite a lot of our information and got ... basically our whole experiment.

When the science fair presentation and judging were over, there was a change in Victor's conception of experimentation. In his last journal entry, which was not dated, Victor wrote:

---

7 Air Care is an annual B.C. government auto emissions test requirement and the name of the facility.

> An experiment now means ... more research, observation, and a lot of thinking. I still believe that experiments have to do with science and is something you learn from. After judging, I have realized that experiments can be modified in ways that the first person did not see and can be changed in many ways by other people's points of view.

In the third interview on March 30, Victor reiterated that his previous understanding of experiment had changed:

> Victor: Ah ... I would think the definition which I had at the beginning was ... quite ... It's not anything you learn from. It [the definition] seems a little too vague.
>
> Before I had a belief that it [an experiment] is anything you learn from but now I believe an experiment has more to do with a basic question to be answered because an experiment can go in different ways.

Victor made reference to how being judged and receiving feedback from the judges had caused him to reconsider his meaning of an experiment. The revised conception of experimentation consisted of moving beyond the everyday sense:

> Victor: Well ... my definition for experiment or experimentation [has] changed. In the beginning I said it's a basically anything that you can learn from. But now I realize after doing the science fair and being judged and hearing feedback from the judges and what they thought, we could have done better in our experiment. I've realized that whatever you learn from that's correct. Yes. But [to do] a well rounded experiment, you should have researched what you're going to be experimenting upon. You should have a basic question [of what] you want to find out about your experiment because you can have thousands of questions which you can base upon that one experiment that you're doing. And I found more of [an] insight ... look at what you're experimenting about. [Research] should be done before you go ahead and experiment on whatever you're doing so you have a better understanding of what everything is before you go ahead and proceed with what you have to do.
>
> Wayne: So you think that you have changed [your definition].
>
> Victor: Basically yah. I think I've changed quite a lot now. Before I thought it was just anything you learn from but I realize now that research and finding out about what your experiment is about can help a lot and give you a better understanding also.

Structured lab activities

In the first interview, Victor said if he followed a structured lab activity and produced the same or similar expected result , then the activity was an experiment. The justifications he gave were that he learned how to perform the activity, learned that he was able perform the activity, and saw the results for himself. Even when an activity did not produce the expected results, the act of performing the activity was still considered an experiment because he believed he would learn that the activity did not always have the same outcome.

In the second interview, Victor repeated the above idea about structured activities:

Victor: So to me that [textbook activity] was an experiment even if they do give all the answers. It's still an experiment because I'm learning something new. And I learned it by doing it hands-on and seeing the observations that I saw.

However in the third interview, Victor equated a structured lab activity to three-fifths of an experiment. In order for a structured lab activity to be a 'complete' experiment the student would need to conduct more research to understand the underlying theories in the activity.

Wayne: So the activities in the textbook, [are they] what you mean by an experiment?

Victor: Yah, they are what I mean by an experiment. But like I've said, if they give you [the] materials, go do it [the experiment] ... in their [textbook's] view, it's an experiment, ...

Wayne: It's you I'm asking ...

Victor: Yah, my way, I would say: 'Okay fine this is an experiment.' But it's not an experiment that I would do and treat it as an experiment, doing the questions and answering [them]. I would say that may be three-fifths of the experiment. But if I had done more research and everything, then I know I have done a full experiment. But the other two-fifths: the research, knowledge of what's happening, why it's happening that I think they don't have. They don't say too much of that in our books and I think that's one down side to the experiments they give us.

Demonstrations

Victor considered demonstrations as experiments in the first interview because he could learn from them:

Wayne: When I was demonstrating the potassium and the sodium, their reactions in water, [was] that an experiment?

Victor: Yah, to me ... well to you it's not an experiment because you've already done it before. When you first [did it], may be it was an experiment. To us, even though we didn't get to do hands-on things, it [demonstration] was still an experiment in which we learned from because now we know that certain reaction can happen.

By the second interview, Victor added that the development of a demonstration was also an experiment:

Wayne: And a demonstration to you is also an experiment?

Victor: A demonstration ya it could be also an experiment. People think when you're developing a backboard for your science fair, they say: 'Oh that's not an experiment. You're just putting paper onto the board and you're done.' But then if you look at it in a totally different way or view. You're going to have to relate to your science fair project. It is an experiment. You're trying. For the person who's developing the board it's an experiment to see how well he can develop this board, his level of creativity, how complex he can make his board. That's all an experiment to the person and his thinking. That's has to do with an experiment. It's still science.

By the third interview, Victor had altered his thoughts on whether a demonstration was an experiment. Again the judging process had an impact on this change:

Victor: In the beginning, I felt like a demonstration yah it's an experiment because I'm learning from it and everything. But then I realized in a science fair if we had a demonstration and we told the judges what we were doing or demonstrating here, I think they wouldn't quite understand or see it as an experiment because there wouldn't be research. And of course I wouldn't have much knowledge on what we're doing there so if I were asked a question I would [be puzzled] and have a confused face because I wouldn't know what you're saying or trying to relate or what question you're trying to say because I haven't done any research.

So I think in the beginning I said yah everything you learn from but now I realize that research and observations and a full question asking everything helps much better ... understand what an experiment is. And a demonstration, I don't believe it's much of an experiment until you understand what you're doing.

Summary

Table 6 provides an overview of the conceptions at each of the interviews for the case of Victor.

Table 6. Summary of results for the Case of Victor

Research Questions	Interview #1	Interview #2	Interview #3
Conceptions of experimentation	• Some form of learning is involved (e.g., know about a concept and/or how to complete a task.)	• More emphasis on learning. (e.g., know about a concept and/or how to complete a task.)	• Some form of learning is involved (e.g., know about a concept and/or how to complete a task.)
	• Hands-on participation	• Hands-on participation	• Hands-on participation
		• To experiment is to test questions.	• Emphasis on researching about how to ask the "right" question and to perform the appropriate test. • Research to develop more background knowledge in the research question.
Conceptions of structured laboratory activities as experiments	• They are experiments but textbook activities have questions to answer and they do not go into the details.	• They are experiments because one can learn something from them. • They are experiments as long as the observations are not given.	• They are 3/5 experiments because textbook activities do not involve research (what and why something happens).
Conceptions of demonstrations as experiments	• They are experiments because one can learn from them.	• They are experiments because no one can do everything exactly the same way. • They are experiments as long as the observations are not given.	• A demonstration is not an experiment until one understands how and why it happens.

Victor's conceptions of experimentation grew in depth with each interview. His initial understanding of an experiment as anything that he could learn from was echoed throughout all three interviews. If Victor learned from an activity, then the activity was an experiment. The greater the amount of hands-on participation, the more likely Victor would say the activity was an experiment. In the second interview, Victor added that an experiment has a purpose and questions to answer. Without the purpose or the research questions, he said his project would simply be a set of definitions on a car's emission parts and functions.

Textbook activities and science fair activities were seen as similar events in that he could learn from them. There were also differences between them. For example, Victor thought textbook activities were simpler and easier to perform than science fair activities. In a textbook activity, there were set questions to answer whereas in a science fair, the questions came from the individual. A textbook activity would be comparable to a science fair activity if the procedure to tell a person what to record or look for was left out.

The word 'research' was dominant in the third interview. The 'research' idea was not mentioned at all in the previous two interviews. To Victor, research meant finding out more information on a topic and experimentation and asking more questions before starting a project. Feedback from the science fair judges had a effect on Victor's conceptions of experimentation.

IV. The Case of Angela

Introduction

Prior to the Sc 9/10 H science fair, Angela participated in two inventions fairs. In a Grade 7 inventions fair, Angela and her partner designed a "sushi roll" made out of candies. In a Grade 6 inventions fair, Angela and two other students assembled a robot. Of the two projects, Angela thought the robot project was more like an experiment than the sushi roll project because the former was more complicated. A rabbit feeder built by a sixth-grader stood out in Angela's mind because she referred to the feeder several times in her journal. She thought it was the best invention at the fair.

In Angela's early journal entries, she considered topics such as: growing plants, astrology, making an invention, growing crystals, and building an intruder alarm for her science fair project. The intruder alarm idea came from Angela's partner (a female student from the same class as Angela and a non-participant in this study). A misunderstanding about the science fair due date led to another change in the two students' choice of project and marked the beginning of the science fair project (building an electroscope and testing for static charge) that they finally conducted.

Angela's November 27 journal entry showed how she decided on the electroscope project. The entry also indicated some of the features she looked for in a science fair project:

> I looked through my book on easy electrical experiments and found one that I thought was intriguing and yet fun to make. It has instructions that I could understand and the materials list was quite small. But I figured it to be complicated enough to be at a Grade 9 standard. I was quite relieved when I found it.

Conceptions of experimentation

There was a constant element in Angela's conceptions of experimentation throughout the science fair. According to Angela, to experiment meant "trying to find out something for yourself." In the first interview on November 2 she described her inventions projects (designing a sushi roll and building the robot) as experiments:

Wayne: Which is more like an experiment? Would making the sushi roll be more like an experiment? The robot? Or the feeder?

Angela: I think all of them was an experiment because like they're sort of trying to find something out. Trying to make something. I think they all are.

Later in the interview, I asked Angela to rank the three projects (sushi roll, robot, and feeder) to see which project was most like what she meant by an experiment. From her ranking, the more complicated the project, the more likely Angela would say it was an experiment:

Wayne: Suppose I didn't have those 4 examples for you to rank. Like 1, 2, 3, 4. And you had to rank the sushi roll, the robot, the feeder ... what else you've done?

Angela: That's it.

Wayne: Suppose you had to rank those three.

Angela: Ah hum.

Wayne: Which one of those three is most like what you mean by an experiment?

Angela: Hum ... I think the robot because like we had to ... it's like the most complicated. And then we had a lot more people to try to help to make it. And then the rabbit feeder is second because like it's so complicated but it's not that complicated. You're still building something. And then the sushi roll third because it was pretty easy and anyone could have made it. So it wasn't really an ... like I don't know ... experiment. I guess it was because we're just trying to find something out. But um it was like already created, the caramel and chocolate and stuff like that.

In the second interview on February 20, Angela's conception of experimentation was like the one she expressed in the first interview. However, she elaborated on that conception by adding that an experiment answers a question:

Wayne: What does it mean to experiment, right at this point to you?

Angela: I think it means to make your own research and then try out something for yourself to find out an answer to a question that you've been wondering about.

Wayne: Ah hum. Which part or parts of your project is most like what you mean by an experiment?

Angela: I think it was the part when where we were testing the electroscope to see if it would conduct or if it could detect static electricity. Because we weren't quite sure if it would work and then we tried it and then it worked.

Wayne: How is that like what you mean by an experiment?

Angela: Because in an experiment you're trying things to find out yourself to see if your answer is correct. And then we were testing our electroscope to find out if our guess was right that it would conduct and then it worked.

Whether nor not the findings of an experiment were 'correct' did not matter to Angela's conception. As long as the individual was finding something out for himself or herself then the activity was an experiment. Angela also struggled with whether a flawed procedure could produce a 'correct' finding and whether an incorrect conclusion could be drawn from a 'correct' procedure:

Wayne: Finding an answer for yourself. Does the answer have to be right?

Angela: No. Not really because ... Well if it's wrong it's still an experiment but then it's not really the right answer so it's not. You don't really know if it's correct or not. Well ... because experiments usually have to find out the right answer. But if it's wrong then you don't really know if it worked or not. But if it ... I don't know. If it's right I guess you don't know if it worked.

Wayne: What did you mean by that?

Angela: Well you usually try to answer your question. So when people experiment ... and I guess when they find out an answer they're not quite ... Well I guess they can be sure it's right sometimes but I don't know if they really know if it's right or not ... their conclusion. Or actually I think if they find out the conclusion it can't really be wrong because they did the experiment and it worked. Well if they got a conclusion then it has to have worked. Then it can't really be wrong because they got the answer.

Wayne: So is that still the same definition that you had at the beginning of the interview.

Angela: Ah hum.

Wayne: You said that an experiment has to have a question and you have to do something. And now ... it has to have the right answer too?

Angela: Well, I guess the answer ... If it's actually right or wrong it can still be correct because you went and experimented and you found out an answer. Well like if you experimented and you found an answer, in my opinion when you're experimenting the answer's right even if it's wrong.

Angela's belief that the result of an experiment does not have to agree with the 'correct' view was repeated at the third interview on March 27:

Wayne: Okay. Is your project less of an experiment if you got an answer that was different from some source like the book?

Angela: Probably not.

Wayne: So even if someone got a different answer than someone else. Let's say when I did [the experiment], [the electroscope's leaves] went up and when you did it, they went down. And one of us is right. Would the other person's experiment be not an experiment?

Angela: No, I think they'd still both be an experiment.

Wayne: Why?

Angela: Why? Well because I tried to find out an answer. It doesn't really matter if it's right or wrong. So if you find out an answer and two people's answers could be different and it could still an answer. That's all you're trying - to find the answer.

Angela's last journal entry dated March 6, five days after the science fair, discussed what experimentation meant to her at that moment:

> An experiment to me means to try out something for yourself, a series of tests maybe, to find out the answer to a question. A more scientific question has a category of sciences - such as physics, chemistry, or biology - that it goes under in my opinion. While testing to find out the answer to an experiment, it is a more "real" experiment if you try it out for yourself firsthand, instead of watching someone else do the tests, and obtain the same answer.

In the third interview on March 27, Angela again repeated basically the same idea of an experiment she had in the first two interviews:

Wayne: How have your ideas about, understanding or definition of experimentation changed throughout this science fair?

Angela: They haven't changed much. Like I still think that an experiment means to go through a series of tests yourself to find out the answer to a question.

Structured lab activities

Angela thought that textbook science laboratory activities were less like an experiment such as building a robot. A textbook activity had less "testing" or "trying out" than an open-ended investigation. However, given a choice between an open-ended investigation and a textbook activity, Angela would prefer the textbook because of the potential danger with an open-ended activity. In a textbook activity, either the textbook or the teacher would warn the student of any hazards:

Angela: And you know all the rules and stuff like what to mix and what not to mix if you're using chemicals. Then outside [of the classroom] if you don't read the rules properly and like no one tells you, you could get injured. (Interview #1)

In the second interview, Angela believed that whether an activity could be considered an experiment is subjective.

Wayne: Is it hard to say whether this is an experiment and this is not an experiment?

Angela: Ah hum. Because it can have a lot of different answers. It depends on the person like what the person's idea of what an experiment is.

Wayne: Who's idea? Like which person?

Angela: Like whoever was thinking about it. Like whoever is answering the question if it is an experiment, if it is not an experiment.

In the third interview, she repeated that structured activities were experiments to her because there was testing and trying to find an answer:

Angela: Okay like you know the book gives us the steps in how to do [the activity]. That's all like close to 1 and a half or a 1 [on a scale of 1 to 4] because we try to experiment. We try to test it for ourselves and then we try to find out the answer.

Demonstrations

Angela's conceptions of experimentation applied to demonstrations as well. In the first interview, she considered demonstrations as experiments:

Wayne: Now I'm just going to give you some more examples. For example like the one I did in class. I had some sodium and potassium and I cut a slice off and showed it to you that it's kind of shiny and it's a metal. Then I put it in water. To you, was that an experiment?

Angela: Yah because it shows you what happens and like what was happening when you were doing it.

In the second interview, Angela thought of demonstrations as "second hand experiments." While referring to Part C, example b of the questionnaire, she said:

Angela: . . . And then for (b) ... he already saw someone explaining and demonstrating it so he was trying it out for himself again but then he already knew the results. He already saw what happened. So it's still like an experiment but then it's like a second hand one.

Wayne: A second hand experiment. Interesting.

Angela: Yup.

Wayne: Interesting. So a second hand experiment is something that you've seen and you're just duplicating it.

Angela: Ya. You've seen someone do it right before your eyes so you knew exactly what you have to do.

Summary

Table 7 provides an overview of the conceptions at each of the interviews for the case of Angela.

Table 7. Summary of results for the Case of Angela

Research Questions	Interview #1	Interview #2	Interview #3
Conceptions of experimentation	• To experiment is to try to find out something by oneself.	• Experiment means to research, to try out something, to find out an answer to a question by the individual.	• Experiment means to research, to try out something, to find out an answer to a question by the individual.
	• The procedure has to be carried out by the individual.	• To test if one's answer is 'correct.' • An activity can still be considered an experiment even if the finding was 'incorrect.'	• An activity can still be considered an experiment even if the finding was 'incorrect.'
Conceptions of structured laboratory activities as experiments	• There is less testing or trying things out as in anopen-ended investigation.	• Whether they are experiments depends on how the individual thinks what is an experiment.	• They are experiments because there was a question and the individual had to find the answer to the question.
Conceptions of demonstrations as experiments	• They are experiments because something happened.	• They are "second-hand" experiments.	• They would be more "real" experiments if the individual carried out the procedure.

In general, Angela believed that her meaning of an experiment stayed relatively the same throughout the science fair. The data supported her view. Her conception of an experiment at all three interviews was an activity where there is hands-on involvement in finding out the answer to a question. This belief was consistent with the ideas expressed in her journal entries. What did change was the length and variety of responses Angela gave at the interviews. The responses were longer and more in-depth at each subsequent interview.

By the end of the science fair, Angela expressed two by-products of her science fair experience:

a) a better understanding of what is an experiment, Angela: I didn't know what the definition was before. Well I guess now I've got a better idea of what an experiment is than before [because] I didn't really experiment that much before. And now I'm actually trying something by myself. I can get a better idea of what it is. (Interview #2)

b) learning more about static electricity from completing her project.

I am looking forward to the end of science fair so all of this stress can be over. But I'll have to admit I learned quite a lot from our experiments. I learned how a static charge was conducted, how to tell if the charge is positive or negative, and how to build an electroscope. I never knew before that static charges were either positively or negatively charged! Although I always did wonder why hair stuck to your face after vigorous rubbing. I will be looking forward to the static electricity section in Grade 10 Physics. Mostly because I know most of the facts already! (February 11 journal entry)

V. The Case of Allen

Introduction

On his questionnaire Allen indicated that he had visited science centres and conducted school science activities but he had no prior experience in a science fair. Allen wrote in his journal entries that he had discussions with his grandfather (a retired Physics teacher) and father (an elementary teacher) about possible topics to investigate for the science fair. After thinking through topics such as charting weather conditions at various locations near his family's winter cabin, exploring the Coriolis effect and Foucault's pendulum, simple harmonic motion, and electric generators, Allen decided to complete a science fair project entitled "The relative electrical conductivity of common household liquids." Help, in the form of research ideas and experimental techniques, was given by Allen's grandfather, and Allen acknowledged and documented the nature of the help in his journal. Even though Allen discussed and worked closely with his grandfather throughout the science fair, his journal entries showed that many of the final decisions were Allen's. His project was one of the top ten projects at the science fair, and it was advanced to the Greater Vancouver Regional Science Fair.

Conceptions of experimentation

Figuring out how to solve a problem was the major theme identified from the analysis of Allen's journal entries and interviews. In the first interview on October 24 Allen had two meanings for the word 'experiment:' to show or try something new, and to figure out how to learn something. The first meaning applied to everyday type situations. For example, being on the rugby team helped Allen determine whether or not he liked the sport and considered the experience as an experiment in the everyday sense. The second meaning applied to figuring out a procedure.

Allen: Like somebody has done [the experiment] before. Somebody did the experiment and found out what happened. Then they recorded what they did: the procedure and stuff. Then they're giving it to you and you can do the same thing. But you don't have to find out the procedure because [the textbook is] telling you what the procedure is. And in an experiment, you have to find out the procedure. All you know is the problem. And you've got to think: 'Oh how should we go about it. How should we control.' And you've got to find out.

While thinking about the idea of an electric generators project, Allen's November 21 journal entry, in a way, summarized his conceptions of experimentation throughout this study:

> I think that if I do use this idea [electric generators], I will possibly find different variables in the project that could be changed. If I experiment with these variables and record and possibly include the results then that would be great because the project would include some experimentation. Actually, I think the whole project will be an experiment because I don't know if it will work or how it will work and I'll have to research to find out how to build one, not just any one it has to be one that's suitable for my purpose.

Another instance of Allen's conception of experimentation was when he debated between a project on electric generators and a project on conductivity. In his December 13 journal entry he, again, equated an experiment to figuring out a way to find an answer on his own:

> The generator idea would just show something that didn't have any variables or present any new information to me. The whole point of an experiment is to find out something new. This information will not be new but it will be new to me. It will still be an experiment because I am not copying someone else's procedure and I am figuring out the best way to find the information out on my own. That is part of the project - the thinking. A large part of my project is the thinking of the procedure. The thinking can never be displayed but the results can.

When Allen learned from a friend that the Science Probe 10 textbook contained an activity similar to his project, Allen tried to modify his project by rephrasing his research question. His December 20 journal entry showed how a particular research question is related to its analysis and conclusion:

> I am also thinking of how I could do the same project and experiment but take a different approach by rephrasing the problem and/or title. Some examples of other titles/problems are: 'How much variation in electrical conductivity is there in different household liquids? Which liquids are most hazardous around electricity?' or more specifically 'Which drinks shouldn't you have around electricity?' All of these merely change the focus slightly and would change the way the data was analyzed and what the conclusion would state but the core problem would still be the same: predicting and determining the relative conductivity of common household liquids.

In the second interview on February 23, which took place one week before the science fair, the meaning of experimentation changed slightly from the first interview. The words "formal" and "informal" were prominent throughout the second interview. A 'formal experiment' involved a presentation to an audience while an 'informal experiment' was equivalent to the everyday sense of experimentation:

> Allen: [Experiment] means just finding out something that you didn't know before. I think there's kind of like two kinds of experiments. There's formal and non-formal. A non-formal one is anything like 'I wonder if this is going to work?' You try it and it does or it doesn't or find out if you're going to like something you're just going to try it. You don't have to worry about any of the other stuff. You just do it and find out what it is. You just kind of keep it in your head. You learn yourself. A formal experiment is where you actually write down and you tell people why you're doing it and what you think might happen and you go about it, scientific way, like you figure out the best way. You actually sit down and think about it for a while. You just don't ... go ahead and do it. So basically [to experiment is] just to find out something you didn't know before.

In the third interview on April 18 which took place after Allen's participation in the regional science fair, Allen added that his fundamental sense of experimentation remained relatively the same. Allen remarked that his experience at the regional science fair gave him a much wider perspective on what a scientific experiment could be:

> Allen: Well I don't think the ideas have changed that much. But at the regional science fair I saw a lot more variety of what experimentation can mean. Like all the different examples. I mean how far how deep you can go. Just from simple questions and right down to really complex question. ... So it's just that there was a big variety of types. Like how deep you can go and different ways of

experimenting. Not different ways but just different depth and you know just different representations of experimentation. What it can mean.

Structured lab activities

Allen did not consider structured lab activities as experiments because he said the textbook provided the necessary background information and procedure. The only unknown was whether the expected results would occur. Allen reiterated in the first interview that figuring out the procedure to solve a question was the crucial aspect of an experiment:

Wayne: I'm just going to check to see if I understand what you mean by an experiment. So, in school you can have experiments and out of school you can still have experiments. In school if you are told what to do like the procedure ...

Allen: No if you're told like find this out like this student [Part C - example c of the questionnaire] was told to find melting point of water then that's all they've said. Then part of the experiment is finding out how you'd found that. So they had to think it through. I mean it's not quite an experiment if they say like ... find out this certain thing and this is how you'd do it. Do this and then this and this. Then it's more like an activity.

And in the third interview, Allen's conception of structured lab activities remained the same:

Wayne: Are the classroom activities, you know the ones that we do from a textbook, are they experiments to you?

Allen: Not, not usually because where they're situated in the textbook. You know you've done a certain chapter. You read all the information and then you got to do this quote activity. Then basically you know what's going to happen. It's probably going to be a demonstration of what you just learned. Now I think more of an experiment is what we did with Mr. Jung [a student teacher] the other day where he just gave us a problem and we had to outline what we needed and how we'd set it up. I mean, it wasn't like startling news or something. We knew how to go about it but it was kind of a small scale experiment.

Wayne: So if you weren't told the results but you were told how to do it, would that be an experiment?

Allen: No, because that's part of the experiment - finding out how to do it, going about it. It's like you've got some big huge equipment thing. You've got to find out this problem and everything is all hooked up and all you have to do is take down numbers. That's not an experiment because you didn't really do much thinking you know. You're just getting the results. Turn the thing on or wind it up or start it going or whatever turn the lights on. Whatever you have to do to start the experiment and then you just record your information. You didn't have to think about how you're going to do it.

Demonstrations

In the first interview, Allen referred to Part C, example b of the questionnaire as a demonstration. His reason matched his conceptions of experimentation described earlier:

> Allen: I put a 4 next to the b because they saw someone do a demonstration and then they tried to do the same thing themselves. It's not really an experiment because they're not finding it out for themselves. Somebody else found it out and they go ... that looks cool, I'll do it. So they're just repeating what someone else did.

The idea that if an individual knew the result to an activity, then the activity was not an experiment was repeated in the interview:

> Wayne: If you're demonstrating and you don't know the answer, is that an experiment?
>
> Allen: I guess so but usually I consider like you know if you're demonstrating something, I usually think demonstrating means you know the answer.

Again in the third interview Allen uttered a similar conception:

> Wayne: And a demonstration is not an experiment.
>
> Allen: No cause you know what's going to happen and it's not a problem. In a demonstration, you don't have a question you want to find out. You're just showing somebody that something does this or does that or this works this way or whatever. But there's no question. You know what's going to happen and you're not trying anything out. You're showing something. Like what you can do is if you did an experiment and you found you built this marvelous thing then you demonstrate it to others and you show them how it works and then you know, this is good and they should buy it or whatever.

Summary

Table 8 provides an overview of the conceptions at each of the interviews for the case of Allen.

Table 8. Summary of results for the Case of Allen

Research Questions	Interview #1	Interview #2	Interview #3
Conceptions of experimentation	• To experiment means to figure out how to learn about something.	• To experiment is figure out how to how to solve a problem.	• To experiment is figure out how to how to solve a problem.
	• To experiment means to try something new.	• There are two kinds of experiments: formal and informal. • Formal means to write down the details to explain everything to people. • Informal means to try things out and keep the experience in his head.	• Experiment means to find out the reasons.
		• To find out what one did not know.	
Conceptions of structured laboratory activities as experiments	• A lab activity is a kind of an experiment that someone else has completed.	• The part of the activity where the procedure and the questions are given is not an experiment. • The observation part of the activity is part of an experiment. • Structured lab activities are not expected to be true experiments because the only unknown is whether the expected results would happen.	• They are not experiments because textbook activities do not involve research (what and why something happens).
Conceptions of demonstrations as experiments	• A demonstration is showing what someone else has found out. • A demonstration is not an experiment because the individual is not finding the result for him/herself. The individual is repeating what someone else did.	• A demonstration is not an experiment because there is no thought into how to arrive at an answer.	• A demonstration is not an experiment because the question is did not come from individual.

Throughout this study, Allen's understanding of experimentation did not alter much. Allen repeatedly emphasized that if he had a question to answer and he designed a procedure to answer that question, then that activity was an experiment. The designing or the "figuring out" of the procedure was particularly important in Allen's notion of an experiment. Participation in the science fair and, especially, the regional science fair broadened Allen's conception of experimentation.

Demonstrations and textbook laboratory activities were not considered experiments. To Allen, performing textbook laboratory activities was not an experiment because the procedures for doing them were given to him in the textbooks. Even though an activity similar to Allen's project existed in his science textbook, Allen was quite firm during the interviews that his project was an experiment. He reasoned that since he had a research question and he developed the procedure for his project, his project was an experiment.

VI. Summary

This chapter presented the data relevant to the research questions as cases. Each case began with a brief history of the student's prior experiences in experimentation. Pertinent data from the students' journal entries, questionnaires, and interviews were used to address each research question. Each case concluded with a summary and chart highlighting the students' conceptions of experimentation.

The next chapter will state the conclusion for each research question, discuss critical issues arising from the study and implications for teaching, and suggest avenues for further research.

CHAPTER 5

Conclusions, Discussions, and Implications for Teaching

"Learning science in the classroom involves children entering a new community of discourse, a new culture; the teacher is the often hard-pressed tour guide mediating between children's everyday world and the world of science" (Driver et al., 1994, p.11).

I. Overview of the chapter

This chapter consists of the conclusions of the study, a discussion of some of the critical issues arising from the study and implications of this study for instructional practice, and recommendations for further research.

II. Conclusions of the study

The purpose of this study was to investigate four Science 9/10 honour students' conceptions of experimentation prior to, during, and after a school held science fair. This study used the students' science fair journals, conceptions of experimentation surveys, and in-depth interviews as data sources. I conducted a theme analysis on the above data to address the research questions. Within the limitations and context of the study, the analysis produced the following conclusions.

Question 1: What are four Science 9/10 honour students' conceptions of experimentation at the start, during, and following a science fair?

At the start of the science fair, all four students (Allen, Angela, Jennifer, and Victor) had an everyday sense of experimentation. Their conception of experimentation was one of trying or carrying out a procedure and learning from the experience. A common theme amongst the students was that there had to be hands-on participation by the students in the learning. However, Allen added that figuring out a procedure to solve a problem was the essence of an experiment.

Approximately one week prior to the presentation and judging of the science fair projects, the students reiterated and elaborated on the conceptions of experimentation they had at the start of the science fair. Allen differentiated between a "formal" (a presentation is required) and an "informal" (tinkering and keeping the results in one's head) experiment. Angela added that an experiment answers a question. Jennifer and Victor placed more emphasis on experimenting as a process of learning. Jennifer also said "creativity" was an element of experimentation.

By the end of the science fair, Angela and Allen claimed that their conceptions of experimentation remained much the same throughout the science fair. The data supported their views. Jennifer added thinking about the feedback of others to her notion of experimentation. Victor said his conceptions of experimentation had changed. He asserted that his initial idea of an experiment as any form of learning was vague. Based on the comments Victor received from the science fair judges, he clarified that an experiment required research to develop more background knowledge, ask the "right" question, and perform the appropriate tests.

Question 2: What is the relationship between these conceptions of experimentation and the students' conceptions of typical science classroom activities?

There was consistency between the students' conceptions of experimentation and their conceptions of typical science classroom activities such as structured laboratory activities and demonstrations. The students used their conceptions of experimentation to say whether they considered structured laboratory activities and demonstrations as experiments. For example, Victor thought that any form of hands-on learning was an experiment, and he considered structured laboratory activities and demonstrations as experiments. Also if a student thought that designing the procedure was a determining factor in an experiment, then the student did not consider typical science classroom activities as experiments. I will elaborate further in the following questions.

Question 2a: What are the students' conceptions of structured laboratory activities as experiments?

Initially all the students thought structured laboratory activities were a simpler form of experiment. Some of the students' thoughts on structured laboratory activities were: just observations, 'copies' of others' works, and rudimentary.

As the Science 9/10 honour course and science fair progressed, the students believed structured activities were experiments or contained parts of an experiments. For examples, Allen said that when an activity provided the procedure and questions, the activity was not an experiment. Angela thought whether an activity was an experiment depended on the individual's meaning of an experiment. Both Jennifer and Victor said structured activities were experiments because the activities were part of the learning process.

By the end of the science fair, all the students kept or added to their initial conceptions of structured laboratory activities as experiments. Angela reaffirmed that structured laboratory activities were experiments because the activities had research questions for the students to answer. Jennifer and Victor provided suggestions on how to make structured laboratory activities more like their conceptions of experimentation. Jennifer said if students were allowed to modify an activity's procedure then the activity would be more like an experiment. Victor said structured activities were three-fifths of an experiment because they lacked research on how and why observations occurred. Allen maintained that structured laboratory activities were not experiments because, like Victor, the activities did not involve figuring out how and why an observation happened.

Question 2b What are the students' conceptions of demonstrations as experiments?

The students' conceptions of demonstrations as experiments were similar to their conceptions of experiments and conceptions of structured laboratory activities as experiments. Also once a student thought a demonstration was an experiment the student continued to hold that view; Victor was the exception in the group. The students also made suggestions on how demonstrations could be modified to correspond more with their conceptions of experimentation.

All through the science fair, Angela thought demonstrations were experiments because someone tried something and a result occurred. She suggested that demonstrations would be more like 'real' experiments if an individual carried out the procedure instead of watching it. Angela called demonstrations "second-hand" experiments.

Allen did not consider demonstrations as experiments because he said there was no new thought put in by the demonstrator. The question as well as the procedure did not come from the demonstrator. If the question and procedure did come from the demonstrator then Allen would consider the demonstration an experiment.

Jennifer also did not think that demonstrations were experiments. Like Allen, Jennifer said demonstrations needed modifications by the demonstrator in order to be considered experiments.

Initially Victor thought demonstrations were experiments because he could learn from them. However after considering the judges' comments, he changed his mind at the end of the science fair. Victor added that a demonstrator needed to understand how and why the demonstration worked before the demonstration could be considered an experiment.

III. Discussion of critical issues arising from the study

Two critical issues originated from the interpretation of the research data:

1. the persistence of the everyday sense of experimentation in the students' conceptions, and
2. how to enable students to take greater ownership of their learning and to make their learning more meaningful for them.

Persistence of the everyday sense of experimentation

In the Science 9/10 course, the students were exposed to the 'scientific method' through structured textbook laboratory activities and their science fair handbook. Also the students were required to present their science fair project findings in the 'scientific method' format. Despite the above experiences, Allen was the only student in this study who made references to the method in his journal entries and interviews. Nevertheless the everyday sense of experimentation (to try or test something) was prevalent in all the students' conceptions of experimentation throughout the study. The constructivist theory of learning can explain these findings.

Using a constructivist framework, researchers identified several learning traits: learners have their own ideas about phenomena, meanings for words, and explanations of why thing behave the way they do; learners' ideas are resistant to change or change in unexpected ways even after formal lessons, and learning is seen as a conceptual change (Bell, 1993; Driver et al., 1994; Kuhn, 1989; Linder & Erickson, 1989). The findings that the students in this study had ideas about experimentation and their ideas were persistent were consistent with the constructivist theory of learning.

Before I begin to explore conceptual change strategies, it would be productive to begin by examining the type of investigation the students conducted for the science fair. This is because I believe there appears to be a link between the type of projects the students conducted and the students' conceptions of experimentation.

As mentioned in Chapter 2, Schauble et al. (1991) distinguish between the engineering and science models of experimentation in students' investigations. Similar to Schön's (1983) experiments in practice, the engineering model focuses on making a desired or interesting outcome occur or reoccur. The science model of experimentation focuses on understanding connections among causes and effects. The four participants' projects in this study can be classified as either the engineering or science model of experimentation.

Jennifer, Victor, and Angela's experimentation approaches could be classified as the engineering model. Jennifer was interested in building a model house to demonstrate solar heating. Her efforts were spent primarily on the construction of the model, and she wanted to answer her question: "How does [solar heating] work?" Victor was interested in learning how to operate emission testing equipment and measuring various cars' exhaust emissions upon the removal of emission control devices. Angela was interested in building electroscopes and detecting static electric charges with them. For all three students, their projects were essentially one of learning how to produce a known result. There was a lack of theory testing in the students' approaches to experimentation. Thus the three students were experimenting in the everyday sense. In this study, the engineering model of experimentation was akin to the everyday sense of experimentation.

Allen was interested in the conductivity of household liquids and his project involved designing the procedure and theory testing. Allen based his predictions on whether the liquid was an ionic compound or a covalent compound. He also made the prediction that the stronger cleaners should conduct more electric current because he said they contained more ions. Allen claimed his results supported his hypotheses. Thus Allen was experimenting more in the scientific sense.

There is a maxim that states: "One tends to teach the way one was taught." Perhaps the students who were interested in producing and seeing an effect did so because that was the type of experimentation they were 'taught' or learned. Schauble et al. (1991) argue that part of the difficulty in getting students to move from the engineering model to the science model of experimentation comes from the way science demonstrations are performed and the reasons for performing them:

> Many teachers try to capture student interest by planning classroom demonstrations and experiments that include exciting or attractive effects. Our findings indicate that this practice almost certainly reinforces the natural inclination of students to interpret the goal of experimentation to be the production of the effect, rather than the understanding of processes that produce the effect (p. 877).

Therefore, educators need to be cognizant of the kind of messages students might take with them after exposure to such activities. To complement classroom demonstrations and experiments, students need to be engaged over their meaning of the nature of science and scientific inquiry. The case of Victor shows that when a student is confronted by judges about his or her meaning of experimentation, the student can think about and move towards a more scientific sense of experimentation.

Enabling students to make their learning more meaningful

Being aware of how students learn is one important aspect of teaching. Creating the situations in which the desired learning can take place presents another challenge for teachers. There are many strategies (concept mapping; prediction, observation, and explanation; and interviews about instances and events) that can help initiate conceptual change in students (White & Gunstone, 1992). Two other methods of engagement that I believe are effective in getting students to express and reflect on their thoughts are: journal writing and student directed investigations.

Journal writing

At the outset of this study, I had hoped that the study would help me critically examine science teaching in general and my teaching practice in particular. This study did help me do both of the above through the use of journal writing. The students' journal writing served as a source of research data for me and a deliberate engagement for the students to think about their conceptions of experimentation.

The duration of this study was the second year I have used journal writing in a science fair class. Compared to the first year, some modifications were made to try to enhance the scope and depth of the students' thoughts. For example the students were not only expected to write down their research data and thoughts in their journals. They were also expected to make connections with their previous journal entries and to maintain a dialogue with me by responding to my comments in their journals. The aim of the comments was not to lead the students to scientific experimentation if such a task was possible. Rather the comments were meant to help the students make explicit their assumptions about a particular procedure or idea and to stimulate the students to think about their conceptions of experimentation and the conceptions' evolution. Baird et al. (1991) showed that such a metacognitive approach is important in science teaching and learning.

In summary, I believed journal writing was 'effective' in this study in at least two ways:

1. The two female participants in this study were less vocal in class compared to their classmates. However, Jennifer and Angela's journal entries showed that they were articulate and thoughtful about experimentation. Journal writing appeared to act as a 'voice' for them and encouraged greater self-expression.
2. Through journal writing, the students were more aware of the interconnectedness among the nature of science, scientific inquiry, and production of scientific knowledge.

Student directed investigations

Student directed investigations such as science fairs provide a more meaningful and personal context for students to begin examining their understanding of the processes of science. These type of investigations have several advantages over textbook lab activities. First there is a greater student involvement in the planning of the investigation. Second students have a greater hands-on role in all aspects of the investigation. Third students are required to defend their methodology and findings to judges. Although the students are required to think critically about their actions throughout the entire investigation, it is at the presentation stage where students defend why a particular procedure was used over another and why certain observations are noted over others.

In summary conceptual change requires the learner to actively think about what he or she is learning and how that learning agrees or conflicts with what has already been learned.

As the learner builds upon his or her prior learning, reflection becomes an increasingly important part of that learning.

IV. Implications for teaching

The findings of the present study suggest several educational implications pertaining to classroom practice and curriculum development. They are:

1. Journal writing can be an invaluable tool in getting students to think about the nature of science and scientific inquiry. A journal format that promotes dialogue between the student and the teacher appears to have a desirable effect on students' conceptions of experimentation.
2. One of the students in this study, Jennifer, was surprised at what she accomplished (constructing a working model). Thus more students need to be given opportunities to design and conduct their own experiments. This is also one of the recommendations of the 1991 BC Assessment of Science Technical Report II: Student Performance Component.
3. Research is an on going activity. Students need to be encouraged and given the opportunity to continue their research after a science fair. This will allow students to probe further their research questions and explore new avenues as a result of discussions with teachers and judges.
4. Teachers need to encourage greater student participation in science exhibitions and competitions. Such activities can stimulate and trigger students' thinking about their conceptions of experimentation.
5. Teachers should invite practicing scientists to speak to students about the work they do and how they go about experimenting. The current junior science textbooks do not delve much, if at all, into how scientists think in their work.
6. Students can learn from each other. An apprentice approach to science fair would be to pair up inexperienced science fair students with more experienced science fair students.

7. Whenever possible, teachers should rework a textbook activity or demonstration to include input from the students. This will enhance students taking ownership of the activity or demonstration and match more closely with students' conception of an experiment.

V. Recommendations for further research

The present study has resulted in the identification of several directions for further research:

1. Due to this study's small sample size, further research is needed to clarify the results. This can be accomplished in at least three ways: (a) member checking, (b) using a larger sample size, and/or (c) tracking students' conceptions for over two or more school years.
2. More research is also needed to examine how writing can shape and support students' understanding of experimentation.
3. The case of Allen deserves further research into intangible factors such as a family's support and influences in a student's conception of experimentation.

VI. My experiences in experimenting (II)

At the start of this thesis, I talked about my prior experiences in experimenting. It would be fitting to end this thesis by reflecting on how this study has affected my understanding of experimentation and teaching.

I believe experimentation in the everyday sense is something everyone does throughout his or her life. To try or test something out is a necessity of living because it provides a basic experiential response to our curiosity - a type of sensory stimulation. Without trying out or testing whether we liked something or seeing the result of an action would leave us with a kind of void or unknown. Thus everyday experimenting gives us the ability to quickly learn first hand for ourselves and construct personal knowledge. However, trying something haphazardly using whatever method is available may be dangerous and may lead one to an 'invalid' or 'incorrect' conclusion. This is where scientific experimentation fits in.

Scientific experimentation provides a more rigorous approach to investigations. It provides a framework for exploring and testing one's curiosity, and reporting and validating one's findings. Scientific experimentation also leads one to imagine situations that are not a part of everyday life and thus promote further investigations. In addition, scientific experimentation exposes to the learner that knowledge is also socially constructed.

This study has also helped me better understand my teacher role in helping students learn science, in particular, experimentation. Students need a variety of experiences to learn about experimentation. The greater the hands-on involvement the closer the activity will match a student's conception of experimentation. No one type of engaging students in thinking about the processes of science will suffice. As the opening quotes in each chapter suggest, science and the teaching and learning of science are complex tasks because they are creations and interpretations of the mind. As such, thinking about how one learns is as important as what is learned.

VII. Summary

This chapter has presented a general overview of the research findings reported in Chapter 4, and has identified some educational implications of the study as well as recommendations for further research.

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Appendix A: Students' Conceptions of Experimentation Survey

[UBC Mathematics and Science Department letterhead appears here]

STUDENTS' CONCEPTIONS OF EXPERIMENTATION SURVEY

Do not write your name anywhere in this survey. You will be given a code.

The purpose of this survey is to find out what you think experimentation is and how you would do an experiment. This is **NOT** a test. There are no right or wrong answers. Please respond openly and honestly.

Note that your participation is optional. Any data collected will be kept confidential. Only you, myself, and my thesis committee members will have access to the data. You may withdraw from this study at any time. Withdrawing from or declining to participate in this study will in no way jeopardize your learning or grades.

This survey will take approximately 20 to 30 minutes to complete. Three subsequent interviews will last approximately 30 to 45 minutes each. The total time required of you will be approximately 3 hours. Please note that by completing this survey, you will be assumed to have given consent. Thank you for your consideration of this study.

Wayne Lau

CODE: ____________________________________ October, 1994.

DIRECTIONS:

- This survey has 5 pages including this page.
- Please make sure that there are 5 pages before you begin.
- There are four sections in this survey.
- Please **read** each section carefully **before** completing.
- You may use a pen or a pencil.

Part A: Background Information.

Read each question and choice carefully and select the choice(s) that apply to you by filling in the circle like this ● .

1. You have been studying science in school for a number of years now. Science can also be done outside of school. Which of the following activities have you done outside of school time? Select all choices that apply to you.

   - O I have visited a science centre (eg., Science World, Vancouver aquarium, planetarium, etc.).
   - O I have completed a science fair project for school.
   - O I have 'experimented' to find out things for myself.
   - O I have studied science at a special 'camp' or workshop.
   - O Other: Please describe briefly. ____________________
   - O I have never done any kind of science activity outside of school.

2. If you have done science experiments on your own time, where did you learn how to do the experiments? Select all choices that apply to you.

   - O I thought up how to do experiments on my own.
   - O I learned how to do experiments from school.
   - O I read books on how to do experiments.
   - O I learned how to do experiments from watching television.
   - O Other: Please describe briefly. ____________________

3. Last year, about how often did **you** do some kind of science activity (demonstrating, experimenting, researching, presenting projects, etc.) in school?

   Last year, I did a science activity in school about once every

   - O class.
   - O second class.
   - O week.
   - O two weeks.
   - O month or longer.
   - O I did not do any science activity last year.

4. Usually who/what provided you with the procedure for doing experiments in school?

   - O The textbook.
   - O The teacher.
   - O Myself.
   - O Other students.

Part B: **Attitudes towards experimentation.**

The following items ask you how you 'feel' about experimentation. Please respond to all **six** pairs of words for each item by filling in the circle that best represents your position on the scale between the pairs.

Example:

Learning how to ride a bicycle is ...

INTERESTING	●	○	○	○	○	BORING
PLEASANT	○	○	○	●	○	UNPLEASANT
VALUABLE	○	○	●	○	○	WORTHLESS
IMPORTANT	○	○	○	○	●	UNIMPORTANT
EASY	○	●	○	○	○	HARD
MOTIVATING	○	○	●	○	○	FRUSTRATING

In the example, the person thinks learning how to ride a bicycle is **very** interesting.

INTERESTING	●	○	○	○	○	BORING

In the example, the person thinks learning how to ride a bicycle is a **little** unpleasant.

PLEASANT	○	○	○	●	○	UNPLEASANT

YOUR TURN!

If you have any questions, please ask before you begin. Otherwise, you may start. Remember to fill in all **six** pairs of words for each statement.

1. Doing an experiment **in** science class is . . .

INTERESTING	○	○	○	○	○	BORING
PLEASANT	○	○	○	○	○	UNPLEASANT
VALUABLE	○	○	○	○	○	WORTHLESS
IMPORTANT	○	○	○	○	○	UNIMPORTANT
EASY	○	○	○	○	○	HARD
MOTIVATING	○	○	○	○	○	FRUSTRATING

2. Doing a science activity (exploration, investigation, experiment, etc.) on my own **outside** of class is or would be . . .

INTERESTING	○	○	○	○	○	BORING
PLEASANT	○	○	○	○	○	UNPLEASANT
VALUABLE	○	○	○	○	○	WORTHLESS
IMPORTANT	○	○	○	○	○	UNIMPORTANT
EASY	○	○	○	○	○	HARD
MOTIVATING	○	○	○	○	○	FRUSTRATING

Part C: What do you mean by experimentation?

There are four science activities below. Please rank them from 1 to 4.

1 = most like what you mean by an experiment.
2 = less like what you mean by an experiment.
3 = even less like what you mean by an experiment.
4 = least like what you mean by an experiment.

Notes: i. You may use a number more than once if you feel that two or more of the following examples belong together.

ii. If none of the following examples show what you mean by an experiment, please give your own example or change any of the examples to show what you mean by an experiment.

Rank:

_____ a) A student has some refrigerator magnets and is curious to see which one is the strongest. The student tests the strength of the refrigerator magnets on some metals found around the house.

_____ b) A student saw someone explaining and demonstrating how to make a "volcanic explosion" using vinegar and baking soda. The student tried to repeat the procedure at home.

_____ c) A student was told to find the melting point and boiling point of water by placing a beaker of ice cubes on a hot plate and measuring the temperature of the ice/water every 2 minutes. Then the student had to plot a graph from the data.

_____ d) A student notices that a rainbow always forms right after a rain shower only when the sun comes out in a particular direction. The student tests his/her theory out by using a garden hose on a sunny day.

If you did not use a "1" in any of the above examples, please give an example of what you mean by an experiment.

An example to show what I mean by experiment is ______________________________

____

____

____

Part D: How would you do an experiment?

Suppose the question for your science fair project is "Do plants like music?"
Describe **clearly** how you would do the investigation.

You may use this blank space for diagrams. If you need more space, use the back of this page.

» End of survey. Thank you for your time. «

Appendix B: Student Handouts to Journal Writing

Science Fair Journals - What to write?

Ideas	Questions	Problems	Contacts	Answers	Solutions
	Feelings		Emotions	Inspirations	

As you work on your science fair project, you will bound to have questions. Your question(s) may be about what to do, how to start, whether the project is going in the "right" direction, etc. One of the purposes of the science fair journal is for you to write down your questions and ideas so that you, myself, and the judges can get a sense of how you tackled your project.

Another reason for journal writing is for you to reflect on how your science fair is progressing. We "reflect" all the time. We may talk about a movie we like or dislike. We may think about how to go about planning for tonight's activities. When we reflect in our minds, we may forget. When we reflect on paper, we cannot forget.

Here are some starting points to help you reflect on science fair:

1. I like this idea because ...
2. Another way to approach this might be ...
3. I wonder why this didn't work. Could it be ...
4. This doesn't seem right. I wonder if ...
5. This is going great. I think it's because ...
6. A connection I can make with this idea is ...

The possibilities are endless. Let's start!

SCIENCE FAIR NOTEBOOK AND JOURNAL BEGIN: Sept. 21/94

"Seeing the connectedness of things is the goal of common learning."
(E.L. Boyer 1982)

» The purpose behind the science fair notebook/journal is for you to store ideas, notes (problems, questions, solutions) and data for your science fair project. It is also a place for you to reflect on how your project is progressing.

» At this time, you should not discard any ideas or questions that interest you or tickle your curiosity. Write down everything.

» Some suggestions to help you get started:

- record things and events you heard, read, saw, or dreamed that caught your attention.
- what was it that interested you?
- ask yourself "what if questions . . ."
- even if you think something is "impossible" or too "weird" write it down.

» Once you have a few ideas written down, think about how you would investigate them.

- Where would you start? Library? Scientists?
- What kind of investigation do you want to do? Experiment? Survey? Demonstration?
- What background information do you need before you begin your investigation?

» For your reflections, you might want to think about how your science fair investigation affects your understanding of what science is, how science is done, how scientific knowledge is generated, etc.

» "You are only limited by your imagination."

Your journals will be collected about once every two weeks. The purpose of this is to help me stay informed of the progress of your science fair project. Also, I might be able to help you clarify any questions or concerns you have. Each journal entry must be dated. Clarity is important in your writings because someone else is trying to understand your thoughts.

Have Fun! :)

Appendix C: Interview Schedule

The interview schedule was an adaptation of Seidman's (1991) model of in-depth phenomenological interviewing. There were three interviews spread over the school year: October 1994, January 1995, and March 1995. These times roughly corresponded to the beginning, midpoint, and end of the students' involvement in their science fair. The first interview focused on the students' prior experience in and conceptions of experimentation. The second interview focused on the details of students' experience on research and experimentation during their science fair. The final interview focused on students' reflection on their meaning of experimentation. All interviews followed a semi-structured format and were tape recorded.

Interview #1 - Some questions that were asked to initiate the discussion on science fairs and past experience in experimentation.

1 a. Tell me about the best experiment you have done (or seen).

   b. What makes that experiment better than any others that you have ever done?

2. What immediately comes to your mind when you hear the word "experiment?"

Interview #2 - Questions that were given to the students prior to the interview. This was done in an effort to give the participants more time to think about the questions in hopes of eliciting fuller responses.

1. What does it mean to experiment?
2. Which part(s) of your project is most like what you mean by an experiment?
3 What is the most interesting experience of your science fair project so far? How did you feel about the experience?

Interview #3 - Questions that were given to the students prior to the interview. This was done in an effort to give the participants more time to think about the questions in hopes of eliciting fuller responses.

1. How have your ideas about, understanding or definition of experimentation changed throughout this science fair? Examples?
2. What does experimentation mean to you?
3. If you were to repeat your project for another science fair, what would you keep and what would you do differently? Why?