# SECONDARY SCHOOL STUDENTS' UNDERSTANDING OF SCIENCE PROCESSES: AN INTERVIEW STUDY



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# SECONDARY SCHOOL STUDENTS' UNDERSTANDING OF SCIENCE PROCESSES: AN INTERVIEW STUDY

by

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## Abstract

For many years educators have recognized the need to identify students' existing beliefs about scientific phenomena because these beliefs often play a major role in the learning of new information, especially when they are at variance with the views commonly accepted by scientists. Beliefs which are inconsistent with scientific consensus are commonly referred to as misconceptions.

Many researchers have reported student misconceptions about a variety of concepts in all disciplines of science. However, no research efforts have explored the range and prevalence of misconceptions about science process skills. Thus, the need to pursue students' conceptions about these skills became apparent. The current study investigated the selected processes of planning experiments, hypothesizing, identifying and controlling variables, inferring, observing, interpreting data and predicting.

Based on interest and participation in science fairs, four groups of eight students from grades 7 to 10 (13 to 16 year olds) were interviewed to identify their conceptions about science process skills. These 32 subjects were grouped as "science fair winners" (group A), "science fair non-winners" (group B), "science fair participants" (group C), or "science fair non-participants" (group D). The interviews were conducted using a semi-structured interview

protocol and each session typically lasted 35 to 45 minutes. All interviews were tape-recorded and subsequently transcribed for later analysis. The transcribed tapes served as the data-base for the construction of conceptual inventories.

Each conceptual inventory contained the subject's actual beliefs about the specific process skills investigated. All conceptions were organized under the specific headings explored and these inventories were used to identify misconceptions held by each subject. Misconceptions common to at least two subjects were tabulated for further discussion.

The data collected indicate that students from all four groups have a very inadequate understanding about the processes of science. A wide range of misconceptions were exhibited by subjects from all groups, regardless of interest and participation in science. Much of the confusion experienced by the subjects appears to have originated from confusion with terms that have common sense meanings and scientific meanings which differ. This was particularly evident with the terms "independent variables", "dependent variables", "controlled variables", and "observing."

Some of the most common misconceptions identified in the study include: A hypothesis is a guess about the outcome of an experiment; an independent variable is one that is separate from, or independent of, the rest of an experiment; an independent variable is the same as a controlled variable; a dependent variable is the opposite of an independent variable; a dependent variable is the same as a controlled variable; controlled variables are those whose effects on an experiment are determined and "controlled" by the experimenter; inferring is the same as observing; an inference is a person's thoughts about a particular phenomenon; observing is seeing or watching what happens; a prediction is a guess about the outcome of an experiment; and a prediction and a hypothesis are the same.

In all, a total of 58 different misconceptions were identified. Some of these misconceptions were held by over 70% of the subjects, while others were expressed by less than 10% of them. The findings facilitated the identification and discussion of several educational implications.

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# CHAPTER 1

# THE RESEARCH PROBLEM

## Overview of the Chapter

This chapter introduces the research problem, establishes a need for the study, discloses the research questions, and identifies possible delimitations and limitations of the study.

## Introduction to the Problem

Some of the major science curriculum changes in the United States and Canada in the 1960s and 1970s were fueled by the widespread recognition of the importance of process skills in science. Gagne (1965) and others suggest that many scientific concepts are more effectively grasped through the operation of process skills, and that the acquisition of these skills should be a major goal of science instruction. This emphasis on process skills prompted science educators and curriculum developers to incorporate these skills into science curricula at all levels, and to develop new science programs where necessary. These programs included Science-A Process Approach (SAPA), the Intermediate Science Curriculum Study (ISCS) materials, the Biological Science Curriculum Study (BSCS) materials and the Physics Science Study Curriculum (PSSC) materials. Each of these new science curricula represented a move from science as content, where the teacher transmits information to passive learners who absorb it, to science as process where learners are actively involved in the learning process. The process skills were identified in S-APA to include (1) the basic processes of observing, inferring, predicting, classifying, using space/time relations, using numbers, communicating and measuring, and (2) the integrated processes of formulating hypotheses, controlling variables, interpreting data, formulating models and experimenting.

More than a decade after this curriculum revolution, the study of students' alternative conceptions of natural phenomena became an international focus of intensive research in science education. A variety of methods were employed to investigate these conceptions, and the multitude of labels that have evolved to refer to these ideas are presently in a state of flux. These labels include naive beliefs (Caramazza, McClosky, & Green, 1981), alternative frameworks (Driver & Easley, 1978), students' errors (Fisher & Lipson, 1986), misconceptions (Griffiths & Grant, 1985), alternative conceptions (Hewson & Hewson, 1984), intuitive beliefs (McClosky, 1983), preconceptions (Novak, 1977) and children's science (Osborne, Bell, & Gilbert, 1983). Because of this proliferation of terms, Posner and Gertzog (1982), suggest, using Kuhn's (1962) terminology, that the field is still in a pre-paradigmatic phase. Although the above terms are often used interchangeably by researchers in the field, they do not necessarily all refer to the same thing.

Driver (1981) suggests that children's beliefs which differ from the contemporary view are alternative frameworks, while misconceptions generally refer to ideas students still harbor after they have been exposed to scientific models and theories and have assimilated the information incorrectly into their conceptual frameworks. Cho, Kahle, and Nordland (1985) define a misconception as "any conceptual idea whose meaning deviates from the one commonly accepted by scientific consensus" (p. 107). Pines and Leith (1981) clearly distinguish between preconceptions and misconceptions. They state that what the student already knows prior to formal instruction represents his or her preconceptions. All the ideas and beliefs the child develops through everyday experiences with the world make up that child's body of preconceptions. On the other hand, Pines and Leith define misconceptions as those preconceptions which are inconsistent with contemporary scientific beliefs. The terms preconceptions and misconceptions are frequently used in the present study, and are intended to have meanings consistent with the definitions provided by Pines and Leith (1981).

The intensification of the quest for information relating to students' preconceptions and misconceptions of scientific phenomena over the past two decades, has generated numerous studies. Many of these deal with concepts in physics. They include heat (Erickson, 1979), force (Osborne & Gilbert, 1980), gravity (Stead & Osborne, 1981), and light (Watts, 1985). Areas studied in the discipline of chemistry include the mole (Duncan & Johnstone, 1979), chemical reactions (Hackling & Garnett, 1985), the particulate nature of matter (Novick & Nussbaum, 1981) and molecules and atoms (Preston, 1988). In the area of biology, studies cover many concepts including the concept of animal (Bell, 1981; Trowbridge & Mintzes, 1988), genetics (Browning & Leham, 1988; Stewart, 1982), the concept of life (Brumby, 1981, 1982; Tamir, Gal-Choppin, & Nussinovitz, 1981), and food webs (Griffiths & Grant, 1985).

These research efforts have revealed many characteristic features about misconceptions, some of which have very significant educational implications. These features have been summarized by Fisher (1985) as follows:

(1) They are at variance with conceptions held by experts in the field.
(2) A single misconception, or a small number of misconceptions, tend to be pervasive (shared by many different individuals).
(3) Many misconceptions are highly resistant to change or alteration, at least by traditional teaching methods.
(4) Misconceptions sometimes involve alternative belief systems comprised of logically linked sets of propositions that are used by students in systematic ways.
(5) Some misconceptions have historical precedence; that is, some erroneous ideas put forth by students today mirror ideas espoused by early leaders in the field.
(6) Misconceptions may arise as the result of: (a) the neurological "hardware" or genetic programming (as in the case of automatic language-processing structures, which may be invoked when "reading" an

> equation); (b) through certain experiences that are commonly shared by many individuals (as with moving objects); or (c) through instruction in school or other settings. (p. 53)

In general, students do indeed come to school with inaccurate views about scientific phenomena which often impair the acquisition of important science concepts. Equally as important, evidence suggests that these preconceptions are frequently resistant to traditional teaching methods (Driver & Easley, 1978), and often remain as a variant part of the individuals' conceptual frameworks.

Some researchers (Anderson & Smith, 1983; Hewson & Hewson, 1983; Posner & Gertzog, 1982) have now begun to recognize the need for the implementation of strategies that help students abandon their unacceptable views about scientific phenomena, so that they can then more adequately develop scientifically accepted conceptions. All of these conceptual change strategies require teachers to be familiar with the range of misconceptions students hold prior to instruction. Yet, this procedure of identifying student misconceptions has been largely ignored by teachers (Osborne & Freyberg, 1985), probably because they are unaware of its importance. However, more and more researchers are identifying misconceptions in different areas, and eventually curriculum developers and textbook writers may identify these in teacher resource books so that science teachers can become familiar with them. This may help teachers to become more effective in fostering conceptual change in their students, thus reducing the negative impact that these misconceptions potentially have on student learning.

The rich body of information resulting from the persistent research efforts over the past 15 years, has clearly illustrated the prevalence and universality of student misconceptions about a wide range of concepts in all disciplines of science. However, an extensive review of the literature revealed no studies identifying specific student misconceptions about science process skills. In light of this finding, the focus of the current study is to identify misconceptions about the processes of science in a sample of secondary school students.

## Need for the Study

Many science educators (Gagne, 1965; Herron, 1970; Neie, 1972; Okey, 1972) have argued that process skills are a vital part of any science program because a firm understanding of these skills is essential to facilitate learning of science content. Others claim that these skills are very important because (1) they are easily generalized to real life situations, (2) process skills curricula more accurately reflect the nature of science, and (3) science curricula which emphasize process skills help foster the development of formal operational abilities in students (Padilla, 1980).

Despite these arguments, research suggests that students have difficulty mastering these skills (Tobin & Capie, 1980) and that teachers often place little emphasis on them

(Harms & Kahl, 1980). Some researchers suggest that one reason why students have difficulty acquiring some of these skills is that they are linked to the students' cognitive abilities (Padilla, Okey, & Dillashaw, 1983; Yeany, Yap, & Padilla, 1986). They further suggest that many of the integrated processes require formal operational thought patterns. However, as previously mentioned, studies focusing on students' specific misconceptions about science process skills have not been reported in the literature. If the development of these skills in students is a major goal of science education (Gagne, 1965; Okey, 1972), serious attention must be directed towards the appropriate attainment of these skills. This effort would be aided by the identification of students' common misconceptions relating to these process skills. Thus, a study is needed to identify student misconceptions related to the common process skills typically found in modern science courses which are intended to emphasize process over content.

Many researchers have recognized the persistent nature of misconceptions, and the importance of identifying them so that they can be modified. Ausubel, Novak, and Hanesian (1978) note that because misconceptions are amazingly tenacious and resistant to change, their identification and unlearning might be the most important factor affecting the acquisition and retention of subject matter content. Others have proposed explanations for the persistence of these misconceptions. Driver (1981) suggests that just as scientists are reluctant to shift to a new paradigm during a scientific revolution, students tend to hold strongly to their misconceptions and are often very reluctant to change their beliefs to be congruent with the scientific consensus. After all, these misconceptions have adequately explained their own experiences for years, and they often see no reason why they should change them.

Research by Anderson and Smith (1982) and Posner, Strike, Hewson, and Gertzog (1982) has shown that several factors contribute to the persistence of students' misconceptions. Most significant of these is the teachers' lack of awareness of the nature and types of misconceptions and alternative conceptions which students bring to the classroom. As Osborne and Freyberg (1985) state, "unless we know what children think and why they think that way, we have little chance of making any impact with our teaching no matter how skillfully we proceed" (p. 13). Therefore, the need for research to identify typical misconceptions relative to science process skills is apparent. Further, the variety and prevalence of misconceptions among our intermediate and senior high school students should be established, because it is only after classroom teachers and other educators become aware of these misconceptions that consistent efforts can be made to modify them.

It is argued that if students are to develop an acceptable understanding of essential concepts and principles of science, teaching strategies need to acknowledge their misconceptions and present scientifically accepted material in ways that encourage them to abandon these existing beliefs (Driver, 1983). In general, conceptual change strategies should be incorporated into teaching efforts to ensure that misconceptions are dispelled and meaningful learning occurs.

Several researchers have proposed theories for conceptual change, all of which are fundamentally based on the prior identification of the students' misconceptions. For these models to be successful, the classroom teacher must be thoroughly familiar with the students' misconceptions so that he or she can assist students in realizing that these views are not scientifically acceptable. The sense of dissatisfaction would then foster conceptual change and set the climate for the learning of accepted views. The present study identifies some common student misconceptions with respect to scientific processes, which will hopefully foster further research in this important area of science education, and ultimately help science teachers to implement effective conceptual change strategies to help dispel process-related misconceptions students bring to their science classes with them.

## Purpose of the Study

The main purpose of the study is to identify misconceptions that high school students have about selected science process skills. Another purpose is to compare the range and prevalence of misconceptions held by students with different levels of interest and participation in science. It is hoped that the findings will help teachers become more aware of the range of misconceptions that students harbor about science process skills, and thereby help to improve the instruction of these skills.

## Rationale for the Study

Because no other research has been reported in this area, a study is warranted. The present study is essentially exploratory in nature, ascertaining the understanding of common process skills in a sample of science students at the secondary school level. It appeared reasonable that a representative sample of secondary students' understanding of science processes could be obtained by selection according to interest and participation in science fairs. Four groups were identified. They included "science fair winners", "science fair non-winners", "science fair participants", and "science fair non-participants." The eight subjects in each sub-group were randomly selected and interviewed. The interview technique was deemed most appropriate because of the richness and quality of data it provides. The results of a pilot study indicated a need for a larger study, and on this basis a semi-structured interview guide was developed and then validated by a panel of experts.

This served as the method of data collection. Specifically, the study identifies process skills misconceptions amongst grades 7 to 10 students with varying levels of interest and participation in science fairs. The findings from this research may help science educators establish the current level of competence in science process skills in our schools, and help guide teaching practices in our science classes. It may also spark educators to develop further interest in this important (and perhaps neglected) area of science programs, and stimulate other research efforts to accrue a body of information in an area that is currently void of research findings. In turn, this may help science teachers to implement the conceptual change strategies necessary to rid students of the misconceptions that will otherwise interfere with the acquisition of important science process skills. In this context, the current study appears to be justified.

## Research Questions

The study was concerned with two research questions as outlined below:

1. What are the misconceptions students hold about science process skills?
2. How do misconceptions vary among students with different levels of interest and participation in science fairs?

## Delimitations of the Study

Although there is little reason to believe so, the findings of this study may not be representative of students elsewhere, since the sample came from only 16 schools under four different school boards with much the same curriculum offerings. Therefore, the results may not be generalized to students with different curriculum experiences in different parts of Newfoundland or elsewhere.

Another consideration involves the data collection method used. It is quite possible that the interview method did not reveal some misconceptions that would have been easily detected using other data collection methods. For example, if the researcher had observed the subjects while carrying out a science investigation, it might be possible that different results might have been discovered.

The sample consisted mostly of grades 8 and 10 students, and therefore any findings might not be representative of the other grade levels present in the study.

Finally, the time lapse between the subjects' participation in science fairs and the interview sessions may have affected the amount and quality of data collected. Although the researcher deliberately delayed interview sessions for one month after each subject's participation in a science fair, if the wait period had been longer (like three or four months) results could have been quite different from those obtained. One would likely get a false representation of the subjects' true conceptions if they were interviewed too soon after they had repeatedly rehearsed their ideas to judges and others at a science fair.

All of these considerations are possible delimitations for this study and potentially reduce the prospect of generalizing any research findings.

## Limitations of the Study

Although interview strategies are still in a state of flux (Posner & Gertzog, 1982), their extreme flexibility provides an abundance and quality of data afforded by no other data collection methods (Osborne & Cosgrove, 1983). "It provides a desirable combination of objectivity and depth, and often permits gathering valuable data that could not be successfully obtained by any other approach" (Borg, 1963, p. 223). Because of these strengths, the semi-structured interview was chosen as the method of data collection in this study. But, despite its perceived effectiveness, there are several problems inherent in this technique which serve as possible limitations in the current study.

Borg (1963) suggests that the very adaptability of the interview leads to subjectivity and possible bias. Guba and Lincoln (1981) state that because the data collection device is a human being, ". . . the technique is highly vulnerable to interviewer bias" (p. 187). No matter how careful, conscious or well trained the interviewer is, the interaction with the respondent results in responses that may not have otherwise been evoked using other methods of data collection, and may not necessarily represent the subjects' true feelings or thoughts.

Another consideration is the difficulty in ensuring the interviewer's consistency over several interviews. The interviewer, expert or novice, will not conduct an interview in exactly the same way each time. Therefore, some subjects may be unintentionally cued towards particular responses that other subjects will not be cued to. This may contribute to discrepancies in the amount and detail of information obtained from each respondent.

A third limitation is the improvement in interviewer skills as the number of subjects interviewed increases. Despite practicing the interview technique in a pilot study, it is highly likely that as more subjects were interviewed, the interviewer became more skilled at uncovering deeply hidden student misconceptions. Thus, earlier subjects may have held misconceptions that were not detected and not reported in the study.

Other limitations of the study originate from the way in which it was designed and conducted. No efforts were taken to ascertain the subjects' academic ability. Therefore, it is conceivable that the sample used in the study had a large number of "above average", "average", or "below average" subjects, and this may affect the number and type of misconceptions obtained. Also, the sampling process may be another limitation. Even though the sample was randomly selected from defined strata, in some cases the subjects used in the study were selected from only three or four possible candidates. This occurred in instances where there were small numbers of gold and silver medal winners at the regional science fair. These factors may inhibit generalization of findings.

## Summary

This chapter has discussed two areas of science education that have received much attention over the past two decades; namely, science as process and student misconceptions in science content. The importance of identifying misconceptions was discussed, and a need for the current study on misconceptions in process skills was established, the strongest argument being the existing neglect of this important area in the research literature.

The next chapter will discuss constructivism as a theoretical basis for both the process of learning and the origin of misconceptions. Emphasis will be placed on the methodologies used to identify student misconceptions and the relevant research literature for the current study will be reviewed.

# CHAPTER 2

# REVIEW OF THE LITERATURE

## Overview of the Chapter

This chapter provides a theoretical perspective for research related to students' misconceptions and focuses on the typical methodologies used in identifying them. Relevant research studies and some of their findings are also presented. This literature review lends further support to the necessity for the present study.

## The Constructivist Perspective

Recently, the mainstream of both cognitive psychology and science education has recognized that knowledge consists of complex networks of information and skills, and that learning of new information is heavily influenced by the existing knowledge of the learner (Shuell, 1987). Thus, there has been a shift from the traditional empiricist view of learning to a constructivist view, which views the learner as actively constructing his or her environment. Writers such as Ausubel, Bruner, Driver, Piaget, and Wittrock add support to the constructivist perspective of learning science. All of them acknowledge the importance of prior knowledge in the process of construction of new learning, and thus provide a theoretical basis for misconceptions research.

The constructivist theory of learning is consistent with Piaget's theory of intellectual development. In his work on cognitive learning, Piaget was concerned with the way children construct knowledge to make sense of their world. In his view, the learner constructs knowledge as he or she actively explores his or her environment, modifying existing mental schema in a continual process of adapting to it.

Bruner views learning as an ongoing process of developing an increasingly sophisticated cognitive structure for representing and interacting with the world. The learner attends selectively to the bombardment of stimuli, and this selective process is based on prior experiences. Thus, each learning situation may result in a different learning experience for each individual, depending on how his or her existing knowledge influences the selection of stimuli to attend to.

Ausubel's (1968) theory of meaningful learning implies that a new piece of information or a new concept will be more easily learned if it can be integrated or subsumed into an existing cognitive structure. Ausubel strongly advocates the importance of prior knowledge in affecting how a student learns, as demonstrated in the following quote: "the most important factor influencing the meaningful learning of any new idea is the state of the individual's existing cognitive structures at the time of learning" (Ausubel & Robinson, 1969, p. 143).

Driver (1983) recognizes the fact that because students have different prior knowledge, there will be many interpretations of the same event. Students will actively select and order information that is related to what they already know. Driver suggests that what is learned in a given situation depends as much on the learner's present knowledge structure and beliefs as on the characteristics of the learning environment. She views the learner as actively interacting with the environment to make sense of it. In short, Driver claims that students are the architects of their own knowledge, and how this knowledge is constructed depends largely on their present knowledge structure.

Wittrock (1974a, 1974b) and Osborne and Wittrock (1983) present a generative learning approach which asserts that the learner actively constructs his or her own knowledge by generalizing links between new information and already existing knowledge. The basis of this theory is rooted in the notion that the learner's memories and information processing patterns influence his or her selection of stimuli. Thus, each learner will receive a different learning experience from the same learning situation because of the variations in the learner's existing concepts and processing strategies.

## Origins of Student Misconceptions: A Theoretical Basis

The constructivist perspective of learning provides a theoretical framework to explain the origin of student misconceptions. This theory draws an important distinction between intuitive (private) knowledge and formal (public) knowledge. Intuitive knowledge encompasses all information acquired and internalized by children as they naturally interact with their environment, and it represents their "own reality." Formal knowledge includes all the information that is imposed on children, usually in a formal setting like a school. This knowledge, which is accepted by consensus, represents "someone else's reality" and is often quite different from the learners' intuitive knowledge which has successfully explained their world for many years.

Fundamental to the constructivist perspective is that prior (intuitive) knowledge can act as a bridge or a barrier to the acquisition of formal knowledge (Pines & West, 1986). If the formal knowledge cannot be linked to the learners' private knowledge, little or no meaning will be gained from the experience. Thus, learners will revert to interpreting the world through their own faulty frameworks, which still at least partially explain most of their experiences. Only when intuitive and formal knowledge become integrated will conceptual growth result. Otherwise, the discrepancy between what the learners believe and the contemporary view enlarges, and misconceptions result.

From a practical perspective, many researchers have suggested several sources of student misconceptions. Head (1986) discusses five causes of misconceptions: (1) from everyday experiences and observations, (2) from confusion about the use of terms which have more than one meaning, (3) from the use of metaphors, (4) from the peer culture, and (5) from the innate origin of some ideas. Shipstone (1984) notes that the use of analogies in the classroom leads to misconceptions. A good example of this is when teachers make an analogy that electricity flows through a circuit like water through a pipe. Solomon (1983) argues that information from the peer culture provides children with informal and often incorrect ideas about science. For example, there is a widespread belief among students that a fire does not burn as well in the sunlight. Preece (1984) suggests that a child may be genetically programmed to interact with the environment in ways that produce informal ideas that are likely to be inconsistent with conventional science and can lead to student misconceptions. Cho et al. (1985) and Mahadeva and Randerson (1982) identify textbooks as a source of student misunderstanding. Books are often inconsistent with respect to terminology and the sequencing of content (Cho et al., 1985). There is also research evidence that teachers unknowingly promote the development of misconceptions in their students. Barrass (1984) suggests that teachers sometimes present material to students that is not entirely correct. Part of the reason for this is that teachers sometimes do not recognize misconceptions in the textbooks they use. Another factor may stem from the fact that many teachers are required to teach subjects in which they have little or no academic training. Angseesing (1978) notes that teacher use of terminology may be another source of misconceptions. Teachers sometimes misuse terms in the classroom and this careless use of language causes confusion and misunderstanding among students. The research seems to indicate that misconceptions are developed and continually reinforced in virtually all facets of life.

Many researchers (Hashweh, 1986; Head & Sutton, 1985; Hewson & Hewson, 1983; Posner et al., 1982) have suggested that while the constructivist theory provides a model for conceptual learning and the origin of misconceptions, it does not address the issue of conceptual change and how to abolish these misconceptions. These researchers suggest that "learning is not simply the addition of new bits of information, but involves the interaction of new knowledge with existing knowledge in order that the new may be reconciled with the existing, if possible" (Hewson & Hewson, 1983, p. 732). Therefore, they argue, expelling student misconceptions is a more detailed procedure than is portrayed by constructivist theory. Several conceptual change models have been formulated and popularized, but according to Hashweh (1986) the best of these is the one proposed by Posner et al. (1982), who discuss conceptual change in terms of accommodation, where students will replace or reorganize central concepts when their existing concepts are unable to allow them to function adequately in a new learning situation. Posner et al. propose four conditions necessary for accommodation (conceptual change) to occur. First, the learner must somehow become dissatisfied with an existing concept. Secondly, the learner must achieve minimal understanding of the new concept and it must be perceived as intelligible by the learner. A third condition is that the new concept must also appear plausible. Finally, it must be fruitful in the sense that the learner views it as useful in a variety of situations (Posner et al., 1982, p. 214). However, Hashweh (1986) still argues that even this model can be improved because it does not adequately explain conceptual change or conceptual stability.

Since research evidence clearly shows that misconceptions are often very resistant to extinction through formal instruction, some researchers (Nussbaum & Novick, 1982; Hewson & Hewson, 1983) have effectively demonstrated the use of conceptual change strategies in eliminating misconceptions from students' conceptual frameworks. Central to these strategies are the three general phases of (1) exposing students' preconceptions, (2) creating conceptual conflict, and (3) encouraging cognitive accommodation.

The research literature and the philosophy underlying this field suggests that our education system will only successfully remove student misconceptions if teachers and educators are aware that they exist. This position is advocated by Strike and Posner (1982) who state that "accommodation is more likely to occur if instruction can be organized so that teachers can spend a substantial portion of their time in diagnosing and correcting errors in student thinking" (p. 239). Thus, our education system will improve immensely if educators begin to think according to the principle espoused by Ausubel (1968) who states that "the most important single factor influencing learning is what the learner already knows. Ascertain this and teach him accordingly" (p. vi).

## Methodological Techniques

Commenting on misconceptions research, Hashweh (1986) notes that there is no general agreement on the aims of enquiry, the supporting theoretical rationale for describing pupils' cognitive commitments, or the techniques used for data gathering and data analysis. Researchers have employed several techniques to ascertain students' understanding of particular areas of interest in science, all of which require verbal and/or written communication between the researcher and the student. These techniques include: clinical interviews with individual students (Erickson, 1979; Preston, 1988); interview-about-instances (Angus, 1981; Osborne & Gilbert, 1980); interview-about-events (Osborne & Cosgrove, 1983); multiple choice instruments

(Haslam & Treagust, 1987; Tamir, 1971); and open-ended or free response items (Mintzes, 1984). These methodologies can be conveniently grouped into two general categories: interviews and paper and pencil tests, respectively. Although both of these data collection approaches have proven quite useful, individual or clinical interviews still tend to be the most popular method used in the study of students' misconceptions (Haslam & Treagust, 1987).

## Clinical Interviews

Evolving from the work of French psychologist Jean Piaget (1929), the clinical interview has been used quite extensively in this area of research in science education. According to Posner and Gertzog, "its chief goal is to ascertain the nature and extent of an individual's knowledge about a particular domain by identifying the relevant conceptions he or she holds and the perceived relationships among these conceptions" (Posner & Gertzog, 1982, p. 195).

Guba and Lincoln (1981) discuss the degree of structure which may be involved in interviewing. Structured interviews have a fixed set of questions that are strictly adhered to, while unstructured interviews are conducted without the use of any preset questions. Interviews used in naturalistic studies relating to misconceptions are virtually all semi-structured because, although they follow preset questions, these questions are flexible and the interviewer is free to ask probing questions or questions to clarify ambiguities in subject responses where necessary. Therefore, the preset questions serve only as a guide and this flexibility is the major advantage of the interview technique (Osborne & Gilbert, 1980). Because the interviewer can rephrase, or modify questions as the need arises, subjects may be able to respond to questions that would have yielded no information otherwise. The interviewer can also take advantage of the subject's responses to ask other questions requiring further explanation, thus facilitating the researcher in uncovering the more deeply hidden student conceptions that would often go undetected using other instrumentation. Finally, the interviewer can note a subject's tone of voice, facial expressions and other nonverbal cues that cannot be detected in other diagnostic methods, and the interviewer can then proceed to reword or ask other relevant questions.

Major disadvantages of the use of interviews include the fact that the success of the interview is heavily dependent on the skill of the interviewer. The data yielded from an interview session are dependent on how skilled the interviewer is in asking questions and probing for answers. Borg (1963) comments that a prerequisite of reliable and valuable interviewing is that the interviewer be well trained. The technique is also very time consuming. Each interview typically lasts 35 to 45 minutes. Then a tremendous amount of time and effort is required to represent and interpret the data obtained from the interview session. This problem is addressed by Guba and Lincoln (1981) who note that the difficulty in data analysis arises because interview results are "unpredictable, and non-aggregatable or non-equivalent over several interviews" (p. 187). However, this technique has received extensive use because the advantages far outweigh the disadvantages and it affords a quality and richness of data unobtainable by use of other methods.

Two closely related modifications of the interview technique include interview-about-instances (Angus, 1981; Osborne & Gilbert, 1980) and interview-about-events (Osborne & Cosgrove, 1983). In the interview-about-instances approach subjects are presented with about 20 cards displaying instances and non-instances of a concept. Subjects have to decide if the image on each card represents an instance or non-instance of the concept, and they are then asked to explain their choices. The interview-about-events approach involves presenting subjects with a practical demonstration of an event, such as water boiling in a kettle, and asking them to explain their observations.

## Paper and Pencil Tests

The many paper and pencil instruments include true and false items and definition of terms (Friedler, Amir, & Tamir, 1987); free response items for subjects to write all they know about the concept investigated (Hallden, 1986);

concept mapping (Novak, Gowin, & Johansen, 1983) and, most popular of all, multiple choice tests (Haslam & Treagust, 1987; Treagust, 1986). The major advantage of these diagnostic instruments is that they can be administered to a large number of subjects. But their major disadvantage is their lack of flexibility, resulting in less detailed data.

One of the more promising paper and pencil instruments is described by Haslam and Treagust (1987), who developed a two-tier multiple choice instrument to diagnose subjects' misconceptions. Haslam and Treagust describe a series of steps to follow in developing this test. First, the course content is described in terms of a set of propositional knowledge statements and these are validated by expert scrutiny. Next, subjects are interviewed or given paper and pencil items using questions based on the propositional statements. These questions provide the researcher with a variety of student alternative conceptions which are then used as distractors in the second tier of the multiple choice instrument. The first tier of the test is a multiple choice item relating to content and the second tier contains student conceptions as distractors and one correct answer as the reason to match the correct answer in the first tier. The final product is then validated once again and reliability is established. The chief advantage of multiple choice instruments is that they can be efficiently administered to a large group of subjects. The main disadvantage is that they do not probe as deeply, thus missing subjects' more representative beliefs about science.

Some researchers (Bell, 1981; Haslam & Treagust, 1987) are now taking advantage of the strengths of both the interview technique and the multiple choice instrument. The interview is used to get an in-depth representation of ideas from a small number of subjects (20 to 30) and then, to determine the prevalence of these ideas on a larger scale, the multiple choice items are used. In fact, this methodology is becoming more popular as attempts are made to refine the data collection methods in this field of science education. It is when paper and pencil tests are used in combination with interviewing that their optimal effectiveness is realized. This diagnostic procedure seems to have promise for use in future misconceptions research.

## Related Research

Although interest in misconceptions has resulted in many studies in the areas of physics, chemistry and biology, no reported research has dealt with the identification of misconceptions about science process skills. However, the development of process skills has not been ignored, and in fact, has received much attention over the past two decades. Four general research thrusts have been identified in this area. These include studies regarding student competencies with process skills, studies demonstrating the effective instruction of process skills, studies describing the development of diagnostic instruments for measuring student success in the acquisition of process skills, and studies discussing the relationship between competency in science process skills and level of cognitive development. This body of literature strengthens the argument for the present study.

Several studies have reported a discrepancy between existing statements about the importance of science process skills and the attention they actually receive from science teachers. Although many educators have strong convictions for a process approach to science, evidence suggests that many students are not exposed to these processes in their science classes, and therefore have a lower competency in these skills.

An extensive study by Stake and Easley (1978) revealed several reasons why students are not competent in process skills. Stake and Easley suggest that processes in science are not promoted because of their dependence on an innovative curriculum, non-text materials, specialized facilities and competent teachers. More importantly, many teachers still feel a great responsibility to teach facts, and other "essential" things that will prepare students for the content to be studied at the next level of schooling. Teachers also feel they are inadequately prepared to teach process skills in science, and an investigation showed that their academic training did not emphasize these skills (Stake & Easley, 1978).

Some researchers (Padilla, Okey, & Garrard, 1984; Peterson, 1978; Quinn & George, 1975; Shaw, 1983; Tomera, 1974) have reported that process skills can be successfully taught at all grade levels. Peterson (1978) reported a study where process skills activities were added to a secondary school physics course. One treatment group was given a verbal learning unit in addition to the regular curriculum. Another group experienced an activity-oriented program with the students actively involved in learning. A third group acted as a control in which students were instructed in the regular physics program which included laboratory activities. The two treatment groups showed much greater gains in scores on process skills items, which indicates that emphasizing process skills does lead to greater competence in these skills.

Another notable study in this area was carried out by Padilla et al. (1984) with sixth and eighth grade students. One treatment group was given a two week introductory unit on integrated process skills and then a process skills activity for one period a week for 14 weeks was added to the regular program. Group 2 was given the same two week introductory unit, but then proceeded with the regular program for the 14 weeks. Group 3 received only the regular "content-oriented" instruction and therefore served as a control group. Results showed a significant difference between group 1 and group 3, particularly with the processes of identifying variables and stating hypotheses.

Various studies have discussed the development of diagnostic instruments for the identification of process skills at all levels of science education (Burns, Okey, & Wise, 1985; Dillashaw & Okey, 1980; McLeod, Berkheimer, Fyffe, & Robinson, 1975; Tobin & Capie, 1982). These instruments have ranged and progressed from curriculum-specific tests (McLeod et al., 1975), to non-curriculum-specific tests (Dillashaw & Okey, 1980). Most notable of these are instruments developed by Dillashaw and Okey (1980) and Tobin and Capie (1982).

Dillashaw and Okey (1980) report the development of a valid and reliable 36-item multiple-choice test for middle and secondary school students of science, the Test of Integrated Process Skills (TIPS). These items relate to five process skills including hypothesizing, identifying variables, operationally defining, designing investigations and graphing and interpreting data. The content of these items were drawn from all areas of science so there was no bias towards any specific science discipline. This instrument takes 30 to 45 minutes to administer and can be used by all secondary school science teachers.

The content validity of the test, the objectivity of the scoring key and the clarity of the items were established by a panel of four science educators. They were given the 36 test items and 12 objectives and asked to identify the three items that corresponded to each objective. There was a 95% agreement on the assignment of test items to objectives. The experts were then required to complete the test to verify the scoring key. The experts agreed with the test developers on assignment of test scores 97% of the time. The test was administered to a sample of 308 students and the measured reliability (Cronbach's alpha) was 0.88.

In 1982, Tobin and Capie reported the development of another of these tests, the Test of Integrated Science Processes (TISP). This 24-item paper and pencil test is intended for students from grades 7 to college level. Extensive efforts were expended to establish reliability and validity of the instrument which tests student competencies in skills related to planning and conducting an investigation. Content validity was established through the use of three science educators who were asked to match each item of the test with one of 12 instructional objectives. The validity coefficient was reported to be 0.99. Objectivity of the test was obtained by determining the proportion of answers selected by the judges which were in agreement with the answers intended. The test was administered to 13 classes of students from middle school and a sample of 109 female undergraduate university students. Three reliability measures were calculated and reported as 0.81, 0.87, and 0.94.

A recent thrust in this area is towards the relationship between process skills competency and level of cognitive development. Studies by Shaw (1983), Tobin and Capie

(1982), Padilla et al. (1983), and Yeany et al. (1986) have reported significant correlations between formal reasoning ability and process skills achievement. The research indicates that some of the more complex process skills like controlling variables and experimenting can only be consistently and successfully learned by students operating at a formal operational stage of cognitive development. However, more extensive research needs to be done in this area to determine the full extent of the proposed relationship.

A tremendous amount of research has been conducted in the area of science process skills, but no research has been carried out to identify students' misconceptions about the processes of science. In light of the staggering amount of research findings indicating the multitude of students' misconceptions relating to a variety of concepts in science, the need to explore students' specific misconceptions in science process skills is obvious. The current study will focus on the identification of students' misconceptions about specific science process skills.

## Summary

This chapter has presented theoretical and empirical considerations relating to the origins of students' misconceptions, and has discussed the methodologies used by researchers to establish the range and prevalence of these misconceptions in various subject areas. Research literature relating to teaching, learning and testing of science process skills was reviewed, with an emphasis on the major research thrusts in this area. Through this review, the need for the present study was further established.

The next chapter discusses the methodological aspects of the current study. Consideration will be given to many areas including sample selection, the research design, the interviewing procedure, the validity and reliability of results and data analysis procedures.

# CHAPTER 3

# METHODOLOGY FOR THE STUDY

## Overview of the Chapter

In this chapter the overall methodology of the study is discussed. Attention will be given to providing a description of the sample, the research design, the development of the interview protocol, the interview procedure, the pilot study, the main study, data analysis procedures, and the issues of reliability and validity.

## The Sample

The sample in the study was composed of 32 secondary school students ranging from grades 7 to 10. Fourteen members of the sample were grade 10 students, 10 were from grade 8 and there were 4 students from each of grades 7 and 9. The subjects were drawn from 16 schools from 4 school boards located on the Avalon Peninsula of Newfoundland. Twenty-four of the subjects came from 8 schools in St. John's, while the remaining 8 subjects came from 8 other schools dispersed throughout the Avalon Peninsula. Nineteen females and 13 males ranging in age from 13 to 16 were interviewed in a one-on-one environment. No efforts were made to ascertain student academic ability, but subjects were grouped according to their interest and participation in science fairs. This grouping process will be explained in detail in a later section.

## The Research Design

The basic purpose of the design was to obtain a representative sample of students reflecting different degrees of interest and capabilities in conducting science investigations. The regional and school science fairs afforded an opportunity to obtain such a sample. For logistical reasons it was decided to keep the sample at about 30 subjects. Four groups were obtained as described below.

The research questions in Chapter 1 and the literature review contained in Chapter 2 served as a guide for the design of the study. On the first day of the regional science fair in St. John's in March, 1989, the author obtained a list of all students with experimental projects in the physical and biological sciences, respectively. After the fair was over, a list of gold and silver medal winners (no bronze medals were awarded) from these two categories was obtained and their schools were identified. Since all student winners were from only eight schools in St. John's, only one subject was randomly selected from the list of winners for each school, thus yielding eight subjects to represent group A in the study. The number of student winners for each school was generally six to eight because: (1) there were two divisions of students for each of the two science categories (junior: grades 7 and 8, and intermediate: grades 9 and 10), (2) each project was often done by two students instead of one, and (3) there was sometimes more than one project selected for a particular medal in a particular category. For example, a silver medal may have been awarded to two projects in the physical science category for the junior division, thus providing more winners to select from. However, in some cases the winner was randomly selected from only three or four possible subjects.

Next, the list of the names obtained on the first day of the fair was used to select the second group for the study. Those students at the regional science fair with projects not judged to be medal winners, were identified for each of the eight schools just discussed. From this list, a student was randomly selected from each school to represent the eight subjects for group B in the study. The author then visited each of these eight schools and obtained a list of all those students who had participated in the school science fair, but did not get selected to attend the regional fair. From this list, students with experimental projects in the physical and biological sciences were identified, and one student was randomly selected from each school to represent the eight subjects for group C. Finally, schools on the Avalon Peninsula that did not have a school science fair were identified and from this list, eight schools were randomly selected. Each school was then visited and one student per school was randomly selected. This provided a total of eight more subjects for a fourth group, group D.

Thus, the selection process resulted in 32 subjects from grades 7 to 10 with varying amounts of interest and participation in science fairs. Group A subjects were those who had participated in the regional science fair and won either a gold or silver medal for their particular division and category. In the study this group has been referred to as the "science fair winners." Group B subjects were those who had participated at the regional science fair but did not win a medal. This group has been labelled the "science fair non-winners" in the study. Group C subjects were those who had completed a science project for their school science fair but did not get selected to attend the regional fair. These subjects have been called the "science fair participants" in the study. Finally, group D subjects were those who had not even participated in a school fair. They had no experience with science fairs, and in the study have been referred to as the "science fair non-participants."

In efforts to answer the research questions outlined in Chapter 1, a three-phase procedure was employed to collect and then analyze the data. In phase one, all subjects were interviewed in a one-on-one situation during regular school hours. In each case a semi-structured interview style was used to question each subject about his or her understanding of the processes of science. Each interview typically lasted for 35 to 45 minutes and was tape-recorded and later transcribed for further analysis. In phase two, each of the transcripts was thoroughly analyzed to identify each subject's ideas for each area in question, and these were organized to form a conceptual inventory for each subject, a technique first used and reported by Erickson (1979). Finally, in phase three the information in each conceptual inventory was carefully scrutinized for the presence of misconceptions, which were then presented in table form to serve as the focal point for discussion.

## Development of the Interview Protocol

A preliminary literature review on science process skills was the basis for the development of a first draft of a protocol of questions to be asked in the interview sessions. These questions were scrutinized by two university science educators and modifications were made according to their comments. Following a procedure suggested by Borg (1963), the guide was then field tested through a series of six pilot interviews with subjects from three schools in St. John's. These grade 7 to 10 subjects were randomly selected from a pool chosen to closely resemble the members of the final study in that they were participants in their school science fair. Each interview was tape-recorded for later analysis. After the two subjects in each school were interviewed, the audio tapes were reviewed and on the basis of these tapes, changes were then made to the guide in an attempt to further improve its validity. Copies of this version of the guide were forwarded to four university science educators and six secondary school science teachers. They were asked to judge the validity of the instrument by analyzing the language level, clarity, and appropriateness of the questions asked. Again, necessary modifications were made and another six science fair subjects from three more schools were interviewed to determine the overall effectiveness of the guide and to improve interviewing skills in preparation for the main study. This effort resulted in a final protocol of questions for the final study.

It should be noted that since the eight subjects in group D did not participate in a science fair, the interview guide was modified slightly but still very closely matched the guide for the other three groups. Subjects in group D were asked to assume they were going to do a project on "the effect of light on the growth of bean plants." A sheet of paper containing a highlighted version of this statement was given to the subjects so they could easily refer to it throughout the interview session if they forgot what the experiment was supposed to be about. Copies of the two interview guides and accompanying data sheets are presented in Appendix A.

The final interview protocols each contained 32 questions which explored selected processes of science. These were organized under several headings in the guides and included questions on experimenting, hypothesizing, identifying and controlling variables, inferring, observing, interpreting data and predicting. Since the guides were to be used for a range of ages and intellectual abilities, they were organized so that some of the questions were stated in two or three different forms (for example, see Question 4 in both guides A and B). This allowed the interviewer to quickly rephrase a question to match the subject's level of comprehension. The first three questions in each guide were very general in nature and were primarily intended to relax the respondents and help make the interview procedure a non-threatening experience. Anderson (1954) suggests that such "warm-up" questions must precede data collection questions to help ensure quality data. Some questions (numbers 7 and 24 in the interview guides) required the subjects to identify examples and non-examples of a particular concept, and provide reasons to justify their decisions. These are somewhat like the items used by Osborne and Gilbert (1980) in their interview-about-instances technique. Others (Questions 26, 29, and 31 from the guides) required subjects to interpret data and use this to make predictions, again justifying their answers each time.

## Interview Procedure

Two or three days prior to an interview session, the interviewer contacted the principal of the particular school and arranged for a visit. Despite the view of some researchers that subjects should be told in advance that they ::e going to be interviewed, subjects in this study were not informed until they were excused from their classes to be questioned by the interviewer. This was an intentional effort to prevent them from rehearsing their understanding of the process skills prior to the interview session. Once arrangements were made with the school administration, the interviewer went to the particular school in the St. John's area and interviewed all three of the subjects who had been selected for that school (the group A "science fair winner", the group B "science fair non-winner", and the group C "science fair participant"). Interviewing was conducted in a quiet, unoccupied room in the school. To help preserve the quality of data collected, efforts were taken to prevent any given interview from continuing into the respondent's recess or lunch period.

At the commencement of each interview, the interviewer informally introduced himself as a high school science teacher and each subject was warmly welcomed. Steps were taken to make the respondent as comfortable as possible to ensure a good rapport and to establish a healthy communication link. The interviewer explained that the purpose for the study was to get an understanding of how and what students think about science and science fair projects. Each subject was told how he or she had been chosen for the study and that other students in the same school and other schools were also being interviewed. They were assured that there would be no right or wrong answers for the questions asked and that the interviewer was only interested in their own thoughts. This was considered important because otherwise subjects might have been reluctant to admit that they did not understand a particular question and might therefore have attempted to give answers to questions they pretended to understand (Borg, 1963). This would have resulted in contaminated data in the sense that they would not be representative of the subjects' true beliefs.

To assist in uncovering the respondents' deepest thought patterns, they were encouraged to "think aloud" and give explanations for the answers they had given. They were also told that this study would in no way affect their performance in any of their school subjects and that the interview information would be kept strictly confidential. After being informed of the necessity for the use of an audio tape-recorder in the study, subjects were asked if they objected to having the session recorded. They were also informed that participation in the study was totally voluntary.

To help relax the respondents and develop a non-threatening atmosphere, opening remarks were very general and involved questions about the title of the project and where the project idea originated (note that the interview procedure was slightly modified for group D subjects). These "warm-up" questions were asked in an informal manner to help break much of the tension that many of the subjects might have otherwise carried with them for much of the interview procedure (Anderson, 1954). This was very important in the current study where subjects were not informed in advance of the interview sessions. Except for group D, questions asked were always related to the subjects' projects, or at least to science fair projects in general. This helped provide subjects with a more secure feeling and fostered the quality of responses given (Gorden, 1956).

Because of the semi-structured nature of the interviews, the interview protocol was used only as a guide and the interviewer freely departed from it when the need to explore a particular response arose. However, the interviewer ensured that all questions in the guide were asked to each respondent, and any probing questions would generate a greater wealth of data. Every attempt was made to ask each question in the guide in exactly the same way, using the same expressions and sequential order for all respondents. However, it proved to be quite a challenge to conduct each session in exactly the same way using the semi-structured format. But the benefits of this technique warranted its use.

Taking advantage of the research suggestions for effective interviewing in naturalistic studies, the interviewer took every precaution to enhance maximum success with the data collection efforts. The interviewer tried to ensure unbiased data by avoiding being too directive or too suggestive in his questioning, and he was always careful not to ask leading questions. When a subject could not answer a particular question, the interviewer provided the subject with sufficient wait-time to gather his or her thoughts and perhaps allow the subject to elicit important information. As Guba and Lincoln (1981) note, periods of silence are one form of probe. "They indicate that the interviewer wants more information and is willing to wait until the respondent is satisfied with his own answers" (Guba & Lincoln, 1981, p. 179). If a question did not yield a response, even after a wait-period, it was rephrased in a simpler form, which often reaped an assortment of useful data that would not have been obtained using less flexible data collection methods. Often, the interviewer would repeat vague responses and wait quietly for the subject to hopefully offer another more detailed and more intelligent reply. Also, a portion of a respondent's answer would sometimes be repeated and left for him or her to complete. This usually prompted more concise responses, thus resulting in a richer collection of data.

Throughout the entire interview, respondents were shown the utmost courtesy, which Guba and Lincoln (1981) suggest "will often salvage almost any kird of interview" (p. 175). At the end of the session (which typically lasted 35 to 45 minutes) subjects were thanked for their cooperation, and the interviewer proceeded to interview the other two subjects at that school. No more than three subjects were interviewed each day because it was felt that the quality and depth of the interview might suffer if too many subjects were questioned in such a short period of time. Also, as mentioned above, it would have been difficult to schedule more than three interviews per day without interfering with recess and lunch periods.

The procedure for group D subjects (the science fair non-participants in the study) involved making arrangements to visit the school on a particular day and a subject was randomly selected from the school list at that time. Except for the previously noted minor modifications in the interview guide, the interview procedure conducted was the same as that described above.

## Pilot Study

As suggested by Borg (1963), the main purpose of the pilot study was ". . . to evaluate and improve the guide and the interview procedure and help the interviewer develop experience in using the procedure before any research data for the main study are collected" (p. 230). This field test also provided some insight into how students think about science process skills and helped the interviewer decide if this technique would yield the data needed. The pilot study was conducted in two phases; six subjects were interviewed each time. In phase one, six subjects from three schools were interviewed for 30 to 40 minutes and the process was recorded on audio tape. After listening to the taped versions of these sessions, the interview protocol was modified for phase two, which involved interviewing six new subjects from three more schools. All subjects closely resembled those in the main study in that they had science projects entered in their school science fairs. These 12 subjects were not included as potential subjects for the main study.

## Main Study

The main study involved interviewing 32 secondary school students from grades 7 to 10. Each interview, which normally lasted for 35 to 45 minutes, was conducted in a one-on-one environment and was tape-recorded for further analysis. To safeguard against scheduling problems and possible contamination of the data, only three interviews were conducted each day. Subjects were asked a series of questions on science process skills which were organized under specific categories. After interviewing for the main study was complete, the tapes were transcribed for further analysis. Initially, three tapes and their corresponding transcripts were forwarded to a university science educator for verification to ensure the accuracy of transcription. Once transcription was complete, each transcript was reduced to a conceptual inventory, which was a compiled list of subject ideas organized under specific process skills categories (see Appendix B for sample transcripts and corresponding conceptual inventories). Each inventory was then used to further reduce the data by identifying broader composite ideas that were inconsistent with scientific consensus. Those misconceptions which were common to two or more subjects were represented in tabular form and served as the basis for discussion.

## Data Analysis Procedures

After a month of interviewing, the data stored on the audio cassette tapes were carefully and accurately transcribed. These transcripts served as the starting point for the analysis of the interview data. Each transcript was carefully scrutinized to identify the subject's conceptions for each category of the topic investigated. These subject ideas were organized into a "conceptual inventory" (Erickson, 1979) which represented his or her particular views of the concept questioned. This technique was deemed appropriate because it not only captured individual subject's ideas but was an excellent way to tabulate the prevalence of these ideas. This allowed for much easier analysis and discussion of the research findings.

Each conceptual inventory represents an organized collection of student conceptions relating to the different process skills explored. For any one skill, more than one conception may have been identified. For example, subjects attempting to define the term "hypothesis" sometimes provided two responses, and these have been represented in their conceptual inventories as statements 2.1 and 2.2. All student conceptions were organized under the appropriate process skills categories. After all inventories were constructed, they were further analyzed and misconceptions were identified for each process skill. The most common of these were then tabulated and served as the basis for further discussion, which is presented in the next chapter.

During the discussion of student misconceptions, efforts were made to quote examples of the subjects' ideas from the transcripts to illustrate the idea being discussed. At the end of these quotes is a letter indicating the group to which that subject belonged. Sometimes subjects' ideas were represented through two or more verbal exchanges with the interviewer and, occasionally, excerpts of these exchanges have been presented to illustrate the subjects' thought patterns for a given topic. This was sometimes necessary to provide the reader with a more complete appreciation of the subjects' beliefs. The combination of these two procedures strengthens the discussion and provides a better sense for the data represented.

## Reliability and Validity Concerns

There is unanimous agreement amongst science educators that validity and reliability measures are essential in promoting a sense of confidence in reported research data.

Yet, the literature indicates that many researchers neglect to establish or report these measures, and they are virtually never reported in studies that collect data via interview techniques. Posner and Gertzog (1982) suggest that one reason for this is that ". . . interview strategies are still undefined and in a state of flux [and] . . . a good deal more work is needed in order to increase [their] applicability and validity" (p. 207). Another reason is that it is more difficult to establish the validity and reliability of an interview than many other data gathering devices (Guba & Lincoln, 1981).

In addressing the absence of validity and reliability measures in interview studies of students' conceptions and misconceptions, Hoz (1983) states that "in the present state of the research on conceptual frameworks, reliability is a rather neglected issue, despite its importance" (p. 161). Regardless of the difficulty of establishing these measures in interview techniques, Sutton (1980) stresses that "reliable techniques are needed, both for finding out about a person's mental patterns and for reporting them on paper" (p. 108). Until efforts are taken to develop valid and reliable interview techniques, there will always be a ". . . real danger of misrepresenting the responses" of the subjects (Lythcott & Duschl, 1990, p. 450).

While the reliability of an interview technique is more difficult to establish than its validity, Guba and Lincoln (1981) make several useful suggestions for establishing both of these measures (which they respectively re-name as auditability and credibility) for this naturalistic inquiry approach. They argue that the naturalistic inquirer must ensure these steps are taken if he or she is to be able ". . . to persuade a methodologically sophisticated peer of the trustworthiness of the information provided and the interpretations drawn from it" (Guba & Lincoln, 1981, p. 103).

## Reliability of the Findings

Reliability is a measure of the level of consistency of a measuring device. It reflects how consistently the measuring device will measure the same quantities in similar testing situations. In order for interview data to be reliable, the actual interview procedure must be reliable. Thus, the research design of the study served as the major approach in establishing and controlling reliability. Although a semi-structured interview style was used, every precaution was taken to ensure that all core questions on the standard interview guide were asked to all subjects in the same sequential order. These questions were asked by a well trained interviewer who attempted to keep the delivery of core questions constant across interview sessions. The interviewer was also fully aware of the dangers of leading questions that direct or suggest a subject response. These efforts controlled and reduced the effects of many of the factors that potentially affect data reliability. The semi-structured nature of the interview allowed the interviewer to appropriately adjust the comprehension level of the questions to the level of the subject being interviewed. This was accomplished by asking the same questions in a rephrased form to enable subjects to respond. This allowed for a protocol of questions that were unambiguous and readily understood.

In an attempt to measure the reliability of the study, two methods were employed. First, the interviewer asked a repeat question during each interview session. This question was asked early in the interview and again at the very end of the session. Comparing the consistency of subject responses to the same question at different stages of the interview, can be an effective way to help document the study's reliability. Using the following formula (Sulzer & Mayer, 1972):

$$\frac{\text{no. of agreements}}{\text{no. of agreements + no. of disagreements}} \times 100\,\% = \%\text{ of agreement}$$

a reliability coefficient of 0.87 was calculated for the responses to these repeat questions.

The second, and perhaps the greatest attempt to measure the reliability of the study was the re-interviewing of eight subjects. Two subjects from each of the four groups were re-interviewed two weeks after their first interview.

This two week wait period was consistently maintained for all subjects re-interviewed, and in light of time restrictions, was considered adequate to eliminate any significant interference from the previous interview. Re-interviewing typically lasted 15 to 20 minutes and the five questions asked to each respondent were varied, but the actual questions selected were drawn from those asked in the initial interview session. Consistency of responses to these questions over the two interview sessions were compared to get a calculated value for the reliability. Using the above formula, the reliability coefficient was measured at 0.84. Both measures of reliability indicate that the interview technique employed in the study provided a consistent measure of student understanding of science process skills.

## Validity of the Findings

The validity of the interview protocol, which is an assessment of the consistency of the instrument in measuring what it purports to measure, is rarely reported. The few researchers who have reported this measure, have typically established it by expert analysis. The validity of the interview procedure in the present study was addressed in several ways. The process by which the interview guide was assembled helped control its internal consistency. As previously discussed, the first draft of the guide was scrutinized by two science educators and improvements were made. It was then field tested through a series of six pilot interviews, which Borg (1963) states ". . . is the best insurance against bias and flaws in design" (p. 230). Changes were made to the guide and it was continually improved and molded into a more valid instrument. Then it was analyzed by 10 science educators and science teachers. They were asked to validate each item of the instrument by judging its presumed relevance to the property being measured. Again, modifications were made and six more pilot interviews were conducted to test its effectiveness and also to improve interviewing skills. The combination of expert analysis and field testing led to the progressive development of the guide, and helped establish the internal validity of this instrument.

Sutton (1980) and Lythcott and Duschl (1990) both express a concern for valid and reliable modes to represent subject responses and ideas. This study has addressed the concern of these authors. As discussed elsewhere, transcribed data were reduced to conceptual inventories of subjects' ideas. Copies of each transcript and corresponding conceptual inventory were distributed to 24 graduate students enrolled in the Master of Education program (Curriculum and Instruction) at Memorial University. All graduates were qualified in the areas of science and education, and the majority of them were science teachers at the secondary school level. They were asked to evaluate each conceptual inventory by deciding if the researcher's interpretation of the subject's conceptions (as represented in the inventory) was consistent with the content of the corresponding interview transcript. This exercise ensured that the conceptual inventories actually contained an accurate representation of the subjects' ideas from the cassette tapes. Each transcript and corresponding conceptual inventory was reviewed by four different graduate students and provided the author with an accurate and validated set of conceptual inventories. These could then be used with confidence to discuss the research findings and draw conclusions from them. Appendix C contains the letter of instructions that was distributed to the graduate students.

## Summary

This chapter has provided a discussion of the methodology of the present study. It has established the target population and the specific procedures used to explore the topic identified. Discussions of the data collection instrument were detailed and the efforts employed to establish reliability and validity of the study were also highlighted. The next chapter presents the data collected during the study and provides a detailed discussion of them.

# CHAPTER 4

# RESULTS AND DISCUSSION

## Overview of the Chapter

This chapter presents the research findings obtained. Misconceptions for each process skills area explored are discussed and presented in table form. These areas include planning an experiment, hypothesizing, identifying and controlling variables, inferring, observing, interpreting data and predicting.

## Introduction

The data presented in this chapter are the result of the culmination of a three-phrase process where transcripts of audio-taped interviews were the starting point for the analysis. These transcripts were reduced to a collection of subjects' conceptions organized under a number of process skills categories to form a set of conceptual inventories. The compiled inventories served as the data-base for further analysis, and misconceptions for specific process skills were identified and tabulated to provide the basis for discussion. Samples of the data and data collection instruments are included in the appendices. Appendix A contains the interview guides and the accompanying data sheets, and Appendix B contains sample transcripts and the corresponding conceptual inventories for one member from each of the four groups in the study.

Misconceptions held by two or more respondents from the sample have been represented in tabular form. However, in most cases only those misconceptions exhibited by more than 10% of the sample will be discussed. The only exceptions to this are if only a total of one or two misconceptions have been identified for a certain area, or if the particular misconception is deemed to have educational significance. Some questions generated no specific misconceptions but did warrant a general discussion, which is provided below. Other items asked the subjects to perform certain tasks and some general comments address their overall performance.

All tables in which the data are presented, have two sections. The top section contains, in order of prevalence, the specific misconceptions that have been identified in the study. The bottom section provides a general summary of the subjects' overall performance on the particular areas questioned. For all but four tables, the bottom portion reports the actual number of subject responses that were judged to be acceptable or unacceptable, and the number of subjects who had no response or gave a response that could not be classified. The lower sections of Tables 2, 9, 10, and 13 were modified slightly because of the nature of the questions asked and the responses evoked.

Tables 2 and 13 contain the misconceptions obtained when subjects were asked to classify a list of six statements as examples or non-examples of a particular concept. Because of the multitude of responses given, the bottom portion of these two tables reports the number of subjects who correctly classified all six statements, the number who correctly classified four or five, and the number who incorrectly classified at least half of them. This provides a general sense of how well the subjects performed in these particular areas.

Tables 9 and 10 contain the misconceptions identified when subjects were asked questions about the process of controlling variables. The bottom section of these tables reports the number of subjects who gave responses that were either acceptable or unacceptable. As well, because many subjects exhibited both an acceptable and an unacceptable response to each question asked, these two tables also report the number of subjects who gave two or more conflicting views.

It should be noted that subjects sometimes exhibited more than one misconception for any given topic. As a result, the number of subject responses that have been classified as misconceptions for each group may actually exceed the number of subjects for that group. This is evident in several of the tables presented in the chapter. Another point of interest is that although there were eight members for each group in the study, sometimes not all of them were able to respond to each question asked. Subjects who did not respond have been accounted for in the appropriate area in the bottom portion of the tables. Yet another noteworthy point concerns the presentation and interpretation of the data. The research findings are presented according to group frequencies, but the findings are meant to be illustrative of the range of ideas rather than to suggest any significant differences between the groups. Therefore, the data should be viewed in this light.

As discussed in Chapter 3, the first three questions in the interview guide were very general in nature and served only to "break the ice" at the beginning of each interview session. Therefore, they are not discussed here because they revealed nothing of interest for the study. The remainder of the chapter presents the research findings obtained from questions related to selected science process skills. Each sequence of questions pursues a specific process skills area, and the data collected for each of these areas is consistently represented in two or more tables. For example, Questions 9 to 12 deal with the subjects' conceptions about the term "independent variable" and the data collected are presented in three different tables. This pattern of presentation facilitates a more effective discussion of the research findings and a more efficient interpretation of them.

## Planning an Experiment

Question 4 in the interview guide asked subjects to list some factors they would likely consider when planning an experiment. No general misconceptions were identified here, although there was a wide range of responses illustrating different levels of understanding. Thus, no table of misconceptions is presented. However, the sophistication of answers was not restricted to one particular group, as a variety of suggestions came from all four sub-groups in the sample. On two occasions it was noticed that subjects from the same school gave very similar answers to this question. For example, in one case a subject responded that planning an experiment involves contacting an expert. The other two subjects from that same school also gave the same response. Perhaps this is an indication of the importance of the teacher in influencing the quality of student understanding of process skills. It was noted that some subjects, particularly those who had participated at the regional science fair, responded more quickly to this question and it rarely had to be rephrased to elicit a response.

## Hypothesizing

Questions 5 to 7 focused on the process skill of hypothesizing. Subjects were required to give a definition of the term "hypothesis" and also had to identify examples and non-examples of hypotheses from a list of statements. Many student conceptions were exposed, and most of these were classified as misconceptions. Because of the wide range of misconceptions, only the most common ones are presented in Tables 1 and 2 below.

## Definition of Hypothesis

When subjects were asked **"What is a hypothesis?"** their responses revealed a variety of misconceptions, and the more popular of these are reported in Table 1. The most frequent belief, Misconception 1.1, was the response that a hypothesis is a guess about the outcome of an experiment or, as one subject suggested, "It's a guess of what you believe will happen" (A). This belief was exhibited by over 45% of the 31 subjects who offered a response to the question. Specifically, 10 of the 16 respondents from groups A and B, and 2 members from each of groups C and D entertained this belief. Another closely related, but somewhat different belief is represented by Misconception 1.2. Seven of the 31 respondents felt that a hypothesis is what someone "thinks" the outcome of an experiment will be. This belief was held by three members from each of groups A and C, with the other proponent of this view coming from group B. No evidence was obtained to suggest that any subjects from group D adhered to this view.

Table 1

The Most Common Misconceptions Relating to the Definition of Hypothesis

| Misconception | Frequency by Group | | | |
|---|---|---|---|---|
| | A | B | C | D |
| **A hypothesis is:** | | | | |
| 1.1 a guess about the outcome of an experiment. | 4 | 6 | 2 | 2 |
| 1.2 what someone thinks the outcome of an experiment will be. | 3 | 1 | 3 | 0 |
| 1.3 a prediction. | 0 | 3 | 1 | 2 |
| 1.4 what happens in an experiment; it's the outcome or answer to a problem. | 0 | 0 | 2 | 4 |
| 1.5 a question or problem you want to solve in an experiment. | 1 | 1 | 0 | 1 |
| 1.6 an experimenter's theory of the outcome of an experiment. | 1 | 0 | 0 | 2 |
| 1.7 a reason why something happens in an experiment. | 0 | 1 | 1 | 0 |
| Number of subjects with an acceptable response. | 0 | 0 | 0 | 0 |
| Number of subjects with an unacceptable response. | 8 | 7 | 6 | 7 |
| Number of subjects who did not respond, or whose response could not be classified. | 0 | 1 | 2 | 1 |

Note: In this table and subsequent tables groups A, B, C, and D each have eight members.

Misconceptions 1.1 and 1.2 were much less common amongst group D subjects. However, these data are somewhat misleading. An examination of Table 1 shows that subjects from groups B, C, and D possessed a greater variety of misconceptions than group A subjects. Members from group D held a multitude of misconceptions that are not even represented in Table 1 because each idea was espoused by only one subject. A sample of the wide range of ideas that members of group D revealed about hypothesizing follows. One subject said that ". . . a hypothesis is an answer to a problem" (D), and another stated that a hypothesis is ". . . a method or purpose" for doing an experiment (D). Yet another respondent said, "It's some kind of conclusion" (D).

Informal discussions with many science teachers at district and regional science fairs have indicated that, in their science classes, the teachers themselves promote the view that a hypothesis is a guess. This may account for the 62% of groups A and B members who harbor Misconception 1.1, and the 25% who held the closely related idea, Misconception 1.2. Since these two groups of subjects participated in the regional science fair, they may have felt it necessary to memorize the teacher's definition of the term "hypothesis" so they could be better prepared for the judging session. If it is true that teachers are defining the term hypothesis in this way, it supports the research findings that teachers can sometimes unintentionally be a source of student misconceptions because they occasionally present material that is not entirely correct (Barrass, 1984). Even some science educators (Funk, Okey, Fiel, Jaus, & Sprague, 1979), and many student texts define a hypothesis as a guess. However, Griffiths (1987) argues that a hypothesis is not a guess, but instead is ". . . a tentative testable explanation of an observed event" (p. 22). It is this definition that has been used to judge the subjects' conceptions of "hypothesis."

Table 1 shows that six of the respondents held Misconception 1.3; namely, that a hypothesis is a prediction. However, as will be clear in later discussions, this belief is very prevalent amongst the sample studied. Because this response was spontaneously given and the issue was not deliberately probed at this stage of questioning, its further discussion is left for a later section of the chapter that deals specifically with predicting.

Misconception 1.4, that a hypothesis is what happens in an experiment, that it's the outcome or answer to a problem, was not expressed by any members from groups A and B. But this belief was exhibited by two of the seven respondents in group C, and four from group D. For example, one subject stated that ". . . a hypothesis you're saying what actually happened" (D), and another respondent said a hypothesis is "what happens in your project . . . how you did your project and what goes on in it" (C).

Also shown in Table 1 are three other misconceptions (1.5, 1.6, and 1.7) held by slightly less than 10% of the sample. Overall, none of the 32 subjects in the sample gave an acceptable definition for the term "hypothesis."

Question 6 in the interview guide asked subjects to state the hypothesis for their project, and many of them responded improperly or very poorly to this question. A science fair winner (group A) stated the hypothesis for her experiment as ". . . girls have more responsibility around the house while boys come home and watch TV. Therefore, girls have a better short term memory" (A). A science fair non-winner (group B) conducted an experiment to test the effect of temperature on humidity level, and suggested that the hypothesis being tested was "if there was a fan or dehumidifier in the house, the humidity would probably be higher." A science fair participant (group C) stated that her hypothesis was: "What acid is there in food?" Finally, a science fair non-participant (group D) suggested that the hypothesis for an experiment was: "Under the effect of sunlight, bean plants should be able to grow" (D).

<u>Identifying Hypotheses Statements</u>

Question 7 asked subjects to identify examples and non-examples of hypotheses from the following list of six statements:

(1) If a person's physical activity increases, his pulse rate will also increase.

(2) If an ice cube melts, tiny invisible particles separate and move further apart.

(3) If the temperature of a liquid increases, the amount of solid it can dissolve will also increase.

(4) If a plant's leaves fade to a pale yellow color, it has probably died because of lack of sunlight.

(5) If the amount of acid rainfall has increased steadily over five years, it is likely that next year's acid rainfall will be greater than ever before.

(6) If there is an increase in the amount of light a cucumber plant receives, there will also be an increase in its growth rate.

After examining the list, subjects selected the examples and non-examples of hypotheses, and provided reasons for their choices. This exercise revealed a large number of ideas on what constitutes a hypothesis statement. It also illustrated that most subjects cannot consistently and correctly identify examples and non-examples of hypotheses. Table 2 shows that the most prevalent belief was Misconception 2.1, where respondents felt that statements containing words of uncertainty are hypotheses because they are guesses. This idea was most common in group A subjects where half of the respondents gave a variety of answers indicating the general belief pattern depicted by Misconception 2.1. Two respondents from each of the other three groups also entertained this idea. One subject felt that statement five ". . . is a

Table 2

The Most Common Misconceptions Relating to Identifying Hypothesis Statements

| Misconception | Frequency by Group | | | |
|---|---|---|---|---|
| | A | B | C | D |
| **Identifying hypotheses:** | | | | |
| 2.1 All statements of uncertainty are hypotheses. | 4 | 2 | 2 | 2 |
| 2.2 Statements of uncertainty are not hypotheses. | 2 | 2 | 2 | 3 |
| 2.3 All statements of fact are hypotheses. | 1 | 2 | 0 | 4 |
| 2.4 Those statements that are difficult to prove are hypotheses. | 0 | 0 | 1 | 2 |
| 2.5 Those statements about events with already known outcomes are not hypotheses. | 0 | 0 | 2 | 1 |
| 2.6 All statements written in the form of "If... will..." are hypotheses. | 0 | 2 | 1 | 0 |
| 2.7 Hypotheses are statements that assume a relationship between two variables. | 1 | 1 | 1 | 0 |
| 2.8 Hypotheses are statements about things not found in books or other sources. | 1 | 1 | 0 | 0 |
| Number of subjects who correctly classified all six statements. | 1 | 1 | 0 | 0 |
| Number of subjects who correctly classified four or five statements. | 3 | 4 | 4 | 0 |
| Number of subjects who incorrectly classified at least half of the statements. | 4 | 3 | 4 | 8 |

hypothesis because he is saying that **it is likely**. So in an indirect way he's taking a guess at that" (A). In response to the same statement, another subject claimed that ". . . they say **it's likely**, so therefore they're hypothesizing" (B).

A directly opposite view is Misconception 2.2, which was given by at least 25% of the respondents in each group. These subjects felt that statements of uncertainty are not hypotheses. One subject stated that "number four isn't [a hypothesis] because . . . it's like you're saying it has **probably** died because of lack of sunlight, but you're not sure of it" (C). Another respondent stated that "if you hypothesize something, you gotta say this is **what will happen**. You can't say **probably** dies because of lack of sunlight. You gotta be sure" (A). These subjects felt that hypotheses are statements that tell exactly what will happen.

One-quarter of all respondents felt that hypotheses are statements of fact (Misconception 2.3). Only one subject from group A expressed this view and it was not evident at all in group C. However, two members of group B and half of the subjects in group D held this belief. One subject responded to statement four by saying, "Yes that's a hypothesis because if a plant gets too much sun or water, it will start to die. That is true; it's a hypothesis" (A). Meanwhile, another subject replied, "I wouldn't say number five is a hypothesis because he's only saying **probably**, and he's not stating it. Like it's not a fact" (D). Finally, one respondent suggested that statement three was not an example of a hypothesis "because it's not true" (D).

Table 2 also shows Misconceptions 2.4, 2.5, 2.6, 2.7, and 2.8, each of which was given by a total of two or three subjects from the sample. More than 15 other misconceptions were identified here, but they were expressed by only one respondent each and were therefore not reported in Table 2. A sample of these beliefs include: "That one could be a hypothesis but it's sort of weak, like it doesn't make a really good one because it doesn't have that **if and then** sort of separation" (A). Another member of the sample said ". . . there is always more than one hypothesis for every experiment" (C), and another response was, "but to a certain degree I feel these are all hypotheses 'cause they're saying **if**, which has to be in every hypothesis" (B).

In summary, only two members of the sample correctly classified all six of the above statements as examples and non-examples of hypotheses. Meanwhile, 19 of the 31 respondents incorrectly classified at least half of the statements.

## Listing Variables in an Experiment

Prior to ascertaining the subjects' conceptions about independent, dependent, and controlled variables, they were asked to state some variables that they felt could have affected the results of their experiments. This question evoked a variety of responses, but no common belief patterns were recognized. Approximately half of the sample responded quite well to the question, and they had no difficulty identifying several variables that could have affected the results of their experiments. Many of these subjects were able to respond to the question immediately after it was asked. Others had difficulty with the question, often requiring it to be asked a second or third time. Even then, only a small number of these subjects managed to identify one or two variables relevant to their experiments. Some of them claimed that they did not know what a variable is. This is illustrated in the following exchange with a subject from group D.

> Interviewer: What would be some variables or factors that could affect the results of this experiment?
>
> Subject: What do you mean by variables or factors?
>
> Interviewer: Okay, certain conditions or factors in the experiment that could vary or change to affect the results of the experiment.
>
> Subject: I don't know what a variable is.

About one-half of the respondents who answered the question quite well, did so by discussing the variables that they controlled in their experiments. However, for some of the subjects the word "control" meant that they had the ability or "power" to decide how each variable would affect the experiment. This view is discussed in a later section that probes the subjects' understanding of controlling variables.

An analysis of the subjects' responses revealed two misconceptions, but they have not been represented in table form because they were expressed by only one subject each. As shown in the following excerpt, one respondent felt that an experiment should have only one variable and it should be well controlled: "We made sure that there was the same amount of each type of chemical in each cup and that's mainly what we concentrated on. There was nothing else. There was only one variable and that was controlled" (B). A group C subject felt that there were no variables in her experiment that could affect the results. The following exchange illustrates this idea:

> Interviewer: Are there some particular variables or factors . . . certain things or conditions that could possibly have affected the way your experiment turned out?
>
> Subject: No, unless the mold never grew on the bread that particular day, right. But it did that time.
>
> Interviewer: So there's no variables that could have affected the results?
>
> Subject: No.

In general, about half of the subjects in the sample responded poorly to a question which asked chem to identify some variables in their own experiments. Part of the reason was because some of the respondents did not know what a variable is. Many of the responses were unacceptable and demonstrated a need for improved understanding in this area.

## **Independent Variables**

Questions 9 to 12 dealt with subjects' understanding of the meaning of "independent variable." Three areas were explored and common misconceptions are reported in Tables 3 to 5. The following paragraphs discuss the data contained in each of the tables.

### Definition of Independent Variable

Question 9, **"What is an independent variable?"**, exposed three misconceptions which are displayed in Table 3. Twelve of the 30 subjects who responded to this question exhibited Misconception 3.1, the idea that an independent variable is one that is separate from, or independent of, the rest of the experiment and has no effect on it. Only one subject from group A, three from group B, and two from group C held this misconception, but it was held by 75% of the members of group D. Typical responses were that it is "the thing in the experiment that's by itself" (D), or "a variable that is by itself and not in a group" (D). A possible reason for the belief pattern represented by Misconception 3.1 is because of the difference between common and scientific meanings of words. Osborne and Freyberg (1985) describe

Table 3

The Most Common Misconceptions Relating to the Definition of Independent Variable

| Misconception | Frequency by Group A | B | C | D |
|---|---|---|---|---|
| **An Independent Variable is:** | | | | |
| 3.1 one that is separate from, or independent of the rest of an experiment; it has no effect on the results of an experiment. | 1 | 3 | 2 | 6 |
| 3.2 one the experimenter cannot change or manipulate in any way. It regulates or controls itself. | 1 | 3 | 3 | 2 |
| 3.3 the opposite of a dependent variable. | 0 | 0 | 1 | 2 |
| Number of subjects with an acceptable response. | 3 | 4 | 2 | 1 |
| Number of subjects with an unacceptable response. | 2 | 4 | 4 | 7 |
| Number of subjects who did not respond, or whose response could not be classified. | 3 | 0 | 2 | 0 |

this problem as "the 'unidentified mismatch' [where] the language of the teacher involves familiar words used with specialist meaning in the science classroom" (p. 34). Hackling (1982) also suggests that the multiple meanings of words used in classrooms lead to student confusion in science concepts. This is clearly illustrated in one subject's response that ". . . independent usually means **on its own**, so an independent variable would be a variable that's out on its own" (D).

Another idea shown in Table 3 is Misconception 3.2, the belief that an independent variable is one the experimenter cannot change or manipulate because it regulates itself. Over 30% of the respondents believed this, and the idea was exhibited by at least one member from each group. It represented almost 38% of the responses from members of groups B and C, and 25% from group D held this view as well. A third misconception was identified for 10% of the subjects who responded to Question 9. This idea, that an independent variable is the opposite of a dependent variable, was only expressed by members of groups C and D, and seems to have some basis in the meanings of the terms "independent" and "dependent." This is illustrated by a group C subject who said "an independent . . . it's like a dependent but they are both opposite words." Another subject said that the independent variable is ". . . sort of like the dependent variable but it's opposite of it" (D). In all, only 31% of the sample provided an acceptable response to Question 9.

Members of group D demonstrated a very poor understanding of this area.

## The Number of Independent Variables in an Experiment

When asked how many independent variables there should be in an experiment, subject responses yielded two misconceptions as shown in Table 4. Misconception 4.1, the idea that the more complicated an experiment is, the greater the number of independent variables it will have, was expressed by six members from the sample. Two members from group A, three from group B, and one from group D held this belief. Four of these six subjects felt that simple, easy projects are not very detailed and therefore have few independent variables. But more detailed and complicated projects will have many of them. As one group B subject suggested, ". . . there can be any number [of independent variables] because it all depends on your project, how involved it is." Another response was "it depends on the project . . . the harder ones will have more than the others" (C). The remaining two subjects felt that the number of independent variables in an experiment depends on what the experimenter is attempting to "prove." They believed that the longer it takes to investigate a particular phenomenon, or the harder it is to obtain the "right" answer from an experiment, the more independent variables there will be. For example, one respondent stated that ". . . you can have as many as you

Table 4

The Most Common Misconceptions Relating to the Number of Independent Variables in an Experiment

| Misconception | Frequency by Group | | | |
|---|---|---|---|---|
| | A | B | C | D |
| 4.1 The more complicated an experiment is, the greater the number of independent variables it will have. | 2 | 3 | 0 | 1 |
| 4.2 Ideally there should be no independent variables in an experiment. | 1 | 1 | 1 | 0 |
| Number of subjects with an acceptable response. | 4 | 3 | 4 | 4 |
| Number of subjects with an unacceptable response. | 4 | 5 | 4 | 4 |
| Number of subjects who did not respond, or whose response could not be classified. | 0 | 0 | 0 | 0 |

need to prove what thing it is you are proving or demonstrating" (A), and the other replied that "there is no set number. It's how much you think would give you the results that were believable . . . or as correct as it could be" (B). Generally, these subjects believed that the more difficult and elaborate an experiment is, the greater the number of independent variables it will have.

Responses to Question 11 also revealed Misconception 4.2, the belief that ideally there should be no independent variables in an experiment. One member from each of groups A, B, and C expressed views equivalent to this belief pattern. When asked how many independent variables there should be in an experiment, one subject answered that there should be "as close to none as possible. The best is to have none" (A). Another subject felt ". . . there should be as little as possible. Really there should be none" (C). Obviously, these subjects had inaccurate ideas about the concept of "independent variable."

Other beliefs about the number of independent variables that have not been reported in Table 4 include: "I say it should be about or approximately six or more" (B), "Around two . . . would be about all you need" (D), and "I don't think there is a set number but you can't go on and on and on. I think probably around three is enough you know for any one of the variables really" (A). These responses are somewhat surprising, given the assumption that science fair students are constantly versed in experimental design and process skill terms like "independent variable."

The idea that an experiment has no set number of independent variables was expressed by 24 members of the sample. This idea has not been represented as a misconception in Table 4 because many scientists and science educators would suggest that, in reality, there may indeed be more than one independent variable operating in a given situation and this cannot be prevented. Any phenomenon investigated may have more than one variable whose effect needs to be established. For example, in the classical investigation of the period of a pendulum, there are conventionally four variables whose effects on the time of swing need to be explored. The three most common of these are length of the pendulum arm, the amplitude of vibration, and the mass of the pendulum. In any one trial of this investigation, only one of the potential independent variables is tested, while the others are held constant. Only through a process of elimination, does the experimenter establish which of the three potential independent variables is truly the independent variable. Therefore, this investigation would have three independent variables, but only one would be tested in any single trial of the experiment. In this light, the response that there is no set number of independent variables in an experiment, cannot be considered a misconception.

However, one would expect that the above view is rarely (if ever) promoted in secondary schools, and students would therefore be quite unaware of it. Rather, in science classes where there is an emphasis on the processes of science, students are presumably taught that a well designed experiment will have all variables held constant except the independent variable, the one being tested. Only by controlling all variables except the independent one, will the investigator be able to observe its true effects on the outcome of the investigation. This view is fundamental to the teaching of process skills, and students, especially those involved in science fairs, should be well aware of it. In this context, the idea that there is no set number of independent variables in an experiment, is a misconception. This is especially true in light of some of the subjects' responses. Many of them felt that the experimenter could change as many variables as he or she deemed necessary for the experiment to be successful. They seemingly had little appreciation for the process of experimenting and the numbers of independent variables there should be in an experiment. As shown at the bottom of Table 4, no more than half of the members of each group provided acceptable responses.

## Comparison of Independent and Controlled Variables

Question 12 asked **"Is an independent variable the same as a controlled variable, or are they different?"**. As shown in Table 5, only 11 members of the sample gave an acceptable response to this question. Statement 5.1 was the most

Table 5

The Most Common Misconceptions Relating to the Comparison of Independent and Controlled Variables

| Misconception | Frequency by Group | | | |
|---|---|---|---|---|
| | A | B | C | D |
| 5.1 An independent variable is the same as a controlled variable. | 1 | 3 | 3 | 4 |
| 5.2 An independent variable is not the same as a controlled variable because it is not manipulated or controlled by the experimenter, but a controlled variable is. | 1 | 2 | 1 | 1 |
| 5.3 An experiment must have at least one controlled variable, but does not need any independent variables. | 0 | 1 | 1 | 0 |
| 5.4 An independent variable is the opposite of a controlled variable. | 1 | 0 | 0 | 1 |
| Number of subjects with an acceptable response. | 4 | 2 | 2 | 3 |
| Number of subjects with an unacceptable response. | 2 | 6 | 5 | 4 |
| Number of subjects who did not respond, or whose response could not be classified. | 2 | 0 | 1 | 1 |

prevalent misconception espoused by the respondents. Eleven of the 29 subjects who responded to the question believed an independent variable is the same as a controlled variable. One subject said the two variables are the same because "they don't change. They're pretty static I guess. They stay the same" (B). Another unusual response was that independent variables are just point form (simplified) versions of controlled variables. The most common reason why subjects felt independent and controlled variables are the same was that the experimenter manipulates (controls) both types of variables. This idea is demonstrated by one subject's comments that "a controlled variable, well that's pretty well what you control and you control an independent variable too" (D), and a group C respondent felt the two variables are the same ". . . because you control the independent variables; you control what happens and that's the same as the controlled." Another subject suggested the independent and controlled variables are the same because "you try to control both in the same way" (D). Except for group A, Misconception 5.1 was held by at least 37% of the respondents from each group.

The belief that independent and controlled variables are different because the experimenter cannot control or change the independent variables, was exhibited by five members of the sample as illustrated by Misconception 5.2 in Table 5. Subjects' comments indicated that they adhere to the belief that controlled variables are those the experimenter manipulates or changes in an experiment, while independent variables are not manipulated by the experimenter. Characteristic responses were, "Well, an independent variable . . . can't be controlled, but it controls itself. A controlled variable can be controlled" (C), and "the independent is what you can't control at all. You can't . . . do anything about what happens. But you can control the controlled variable" (A). This idea was expressed by only one member from each group except group B, where two subjects supported this view.

Two other ideas shown in Table 5 are represented as Misconception 5.3, the belief that an experiment must have at least one controlled variable but does not need an independent variable, and Misconception 5.4, that an independent variable is the opposite of a controlled variable. These two views were each espoused by two subjects in the sample. In all, 21 members of the sample were unable to provide an accurate comparison of independent and controlled variables.

## Dependent Variables

Items 13 to 16 in the interview protocol questioned the understanding of the term "dependent variable." The pattern established when pursuing the subjects' understanding of the term "independent variable", was maintained when questioning the subjects about the term "dependent variable." Subjects were asked to provide a definition of the term "dependent variable", to comment on the number of them there should be in an experiment, and to compare this term to the concept of "controlled variable." Misconceptions expressed by two or more subjects in the sample have been illustrated in Tables 6 through 8 and the information in each table is discussed in turn.

## Definition of Dependent Variable

Question 13 in the guide asked, **"What is a dependent variable?"**. Table 6 shows that the most popular belief was Misconception 6.1, namely, that a dependent variable is the opposite of an independent variable. This idea represents the same belief as depicted by Misconception 3.3 in Table 3, but it was a more frequent response to Question 13 than to Question 9. It is included here to preserve the consistency of presenting the diversity of misconceptions exhibited by respondents to each particular question asked. Misconception 6.1 was expressed only by one subject from all of the members of groups A and B, but represented at least 25% of the responses for each of groups C and D. Four other statements in Table 6, Misconceptions 6.2, 6.3, 6.4, and 6.5 were each expressed by less than four members of the sample, but they are worth noting here. Misconception 6.2 represents the belief that a dependent variable is one that does not change during an experiment, while Misconception 6.3 states that a dependent variable is one that the experimenter

Table 6

The Most Common Misconceptions Relating to the Definition of Dependent Variable

| Misconception | Frequency by Group A | B | C | D |
|---|---|---|---|---|
| **A Dependent Variable is:** | | | | |
| 6.1 the opposite of an independent variable. | 1 | 0 | 2 | 2 |
| 6.2 one that stays the same throughout an experiment. | 1 | 0 | 1 | 1 |
| 6.3 one that the experimenter can change or control in an experiment. | 1 | 2 | 0 | 0 |
| 6.4 one that depends only on the independent variable. | 0 | 0 | 1 | 1 |
| 6.5 one that does not depend on other factors. | 0 | 0 | 0 | 2 |
| Number of subjects with an acceptable response. | 3 | 3 | 2 | 1 |
| Number of subjects with an unacceptable response. | 5 | 5 | 5 | 6 |
| Number of subjects who did not respond, or whose response could not be classified. | 0 | 0 | 1 | 1 |

changes or "controls" in an experiment. Misconception 6.4 depicts the idea that a dependent variable is one that depends only on the independent variable, and Misconception 6.5 describes the view that a dependent variable is one that does not depend on other factors. These statements exemplify the types of conceptions that members of the sample held about the meaning of the term "dependent variable." Collectively, the misconceptions represented in Table 6 indicate substantial confusion about the term "dependent variable." Almost 72% of the sample were unable to provide an adequate definition of this term.

## <u>The Number of Dependent Variables in an Experiment</u>

Table 7 illustrates the range and prevalence of misconceptions held by the sample when asked **"How many dependent variables should there be in an experiment, or is there a set number?".** Three misconceptions were identified. At least one member from each group (except group D) held all three misconceptions. Misconception 7.1, that more complicated experiments have more dependent variables, parallels Misconception 4.2 in Table 4 because in both cases the subjects felt that more complex experiments have more variables. Although experiments can certainly have more than one dependent variable, it does not follow that more difficult or complicated experiments will always have more

Table 7

The Most Common Misconceptions Relating to the Number of Dependent Variables in an Experiment

| Misconception | Frequency by Group A | B | C | D |
|---|---|---|---|---|
| 7.1 The more complicated an experiment is, the greater the number of dependent variables it will have. | 2 | 3 | 1 | 1 |
| 7.2 An experiment can have only one dependent variable. | 1 | 2 | 3 | 1 |
| 7.3 The number of dependent and independent variables in an experiment will be the same. | 2 | 1 | 1 | 0 |
| Number of subjects with an acceptable response. | 2 | 2 | 2 | 5 |
| Number of subjects with an unacceptable response. | 4 | 6 | 6 | 3 |
| Number of subjects who did not respond, or whose response could not be classified. | 2 | 0 | 0 | 0 |

dependent variables than easy, less complicated experiments. Responses typifying Misconception 7.1 include the reply of a group D subject who stated, "Well there could be any amount I suppose. Well there's no set number. The more involved the project is the more you got," and another response was "I don't really think there is a set number. It depends on the type of experiment you have" (A). Yet another subject suggested that "there is no set number. It depends on the project; the harder ones will have more than the rest" (C). Misconception 7.1 represented at least one-third of the responses from members of groups A and B, with only one member from each of groups C and D expressing this belief.

An equally prevalent notion was Misconception 7.2, that an experiment can have only one dependent variable. This idea was exhibited by one respondent from each of groups A and D, by three members of group C, and two from group B. The response of one subject suggested a possible source for this misconception: "Our science teacher told us that we were only allowed to have one. Only one independent and one dependent" (C). Science teachers probably present the view that for each independent variable there will be only one dependent variable; only one effect will be noticed by changing only one variable. Thus, students are unintentionally misled into thinking that each experiment will have only one dependent variable. This would also account for the notion portrayed by Misconception 7.3, that for every independent variable there will be exactly one dependent variable. Thus, it is quite plausible that the belief patterns represented by Misconceptions 7.2 and 7.3 are inadvertently advocated by science teachers and the science materials they use while imparting information about the process skills.

Overall, only two members from each of groups A, B, and C, and five members from group D adequately responded to Question 15. The five subjects from group D felt that there is no set number of dependent variables in an experiment. But this idea was expressed by fewer members from the other three groups.

## Comparison of Dependent and Controlled Variables

Table 8 displays subjects' conceptions regarding the comparison of dependent and controlled variables which are inconsistent with the scientific view. These conceptions were exposed when students were asked Question 16 from the guide, which required respondents to compare these two types of variables. Misconception 8.1, that a dependent variable is the same as a controlled variable, was supported by over one-quarter of those who responded to the question. The following excerpt from one subject's transcript suggests one reason why subjects believe this notion: "Because dependent variable you are controlling it, and controlled variable you are controlling it too" (B). But perhaps the most common reason was that "they're what you're not gonna

Table 8

The Most Common Misconceptions Relating to the Comparison of Dependent and Controlled Variables

| Misconception | Frequency by Group | | | |
|---|---|---|---|---|
| | A | B | C | D |
| 8.1 A dependent variable is the same as a controlled variable. | 1 | 2 | 2 | 2 |
| 8.2 A dependent variable is the opposite of a controlled variable. | 0 | 2 | 0 | 0 |
| Number of subjects with an acceptable response. | 6 | 2 | 4 | 3 |
| Number of subjects with an unacceptable response. | 1 | 5 | 2 | 3 |
| Number of subjects who did not respond, or whose response could not be classified. | 1 | 1 | 2 | 2 |

change. They're what you're gonna keep the same throughout the experiment" (D). Subjects suggested that controlled variables are those the experimenter manipulated in an attempt to control them, just like dependent variables. This misconception was held by one respondent from group A and by two respondents from each of the other three groups. The notion that a dependent variable is the opposite of a controlled variable, Misconception 8.2, was held by two members from group B and was not exhibited by any other respondents. Table 8 also shows that six members from group A expressed acceptable views about the comparison of dependent and controlled variables. Two members from group B, four from group C, and three from group D also provided acceptable responses to Question 16. However, one subject from group A, and two from each of groups C and D could not respond to the question. Overall, 53% of the sample provided inadequate comparisons of dependent and controlled variables.

## Controlling Variables

In efforts to reveal the range and prevalence of misconceptions the sample held about the process of controlling variables, subjects were asked Questions 17 through 20 from the interview guide. These questions focused on the meaning and importance of controlling variables in an experiment. The data obtained vividly show that many of the subjects have an inadequate understanding of this process. Tables 9 and 10 and the ensuing discussion discloses the common misconceptions exhibited by the sample.

**Definition of Controlled Variables**

The belief patterns in Table 9 represent the most common misconceptions identified when subjects were asked Questions 17 (**"What is a controlled variable?"**) and 18 (**"What does it mean to control variables in an experiment?"**) from the interview guide. Misconception 9.1, the idea that controlled variables are those whose effects on an experiment are determined by the experimenter because he or she manipulates or changes them by choice, represents one of the most prevalent misconceptions identified in the entire study. As indicated in Table 9, this response was given by over 70% of the sample with at least 57% of the respondents from each group entertaining this belief. Selected excerpts of responses to probing questions exemplify the range of ideas that are represented by Misconception 9.1. One subject argued that the amount of sunlight a plant gets in an experiment could be a controlled variable ". . . 'cause you can put one in the window and one just out of a window and one in the shade somewhere" (D). When asked how he would ensure the amount of sunlight in an experiment was controlled, another subject responded "I'd control sunlight by having plants closer to the window, far away from the

Table 9

The Most Common Misconceptions Relating to Controlling Variables

| Misconception | Frequency by Group A | B | C | D |
|---|---|---|---|---|
| 9.1 Controlled variables are those whose effects on an experiment are determined by the experimenter. He or she manipulates or changes them by choice. | 7 | 5 | 4 | 6 |
| 9.2 A controlled variable is the same as an independent variable. | 0 | 3 | 2 | 4 |
| 9.3 A controlled variable is the same as a dependent variable. | 0 | 2 | 2 | 2 |
| 9.4 Controlling variables involves organizing an experiment so it is very easy to do and understand. | 2 | 0 | 1 | 0 |
| 9.5 An experiment is well controlled if it has few variables. | 1 | 0 | 0 | 1 |
| Number of subjects with acceptable responses. | 1 | 2 | 2 | 1 |
| Number of subjects with unacceptable responses. | 3 | 4 | 2 | 4 |
| Number of subjects with two or more conflicting responses. | 4 | 2 | 3 | 3 |
| Number of subjects who did not respond, or whose responses could not be classified. | 0 | 0 | 1 | 0 |

window, no light at all, and more light than others" (D). A subject from group A discussed controlling variables by saying that "you control how much hydrochloric acid you use, and how much ammonia you use . . . you know, you control how much to use," and another respondent said that the grade of oil used in her project was a controlled variable because she ". . . changed it when [she] wanted to" (A). One other subject stated that "I guess it means that you can control them, like if you want to change them, you can. If you don't, you don't" (B).

Worthy of note is that some respondents seemed to have an acceptable understanding of controlling variables by recognizing the need to have all variables in an experiment kept constant, except for the one being tested. However, probing questions revealed that their ideas were often superficial, and their deeper belief patterns corresponded to Misconception 9.1. This is well illustrated in the following exchange with one subject from group A:

Interviewer: When students talk about how they controlled certain variables in their experiments, what are they really saying? What do they mean?

Subject: They're saying they kept it the same, the conditions the same as much as possible.

Interviewer: What are you doing when you attempt to control variables in an experiment?

Subject: You decide what the variable is going to do, what kind of part it's going to play in the experiment and what variables you use and everything like that.

These subjects seemed to understand the process of controlling variables, but further questioning indicated that the underlying views were inaccurate. As shown in the bottom portion of Table 9, 12 subjects from the sample held these conflicting views.

Misconception 9.2, the idea that controlled variables are the same as independent variables, was expressed by almost 30% of the respondents. Although no members from group A held this view, it was exhibited by at least two members from each of the other three groups. When asked why a controlled variable is the same as an independent variable, one subject suggested it is because the experimenter ". . . controls the controlled variable and controls the independent variable too" (C). All but one of the respondents who held Misconception 9.2 gave answers similar to this. Two members from each of groups B, C, and D expressed views corresponding to Misconception 9.3, that controlled variables are the same as dependent variables. When asked why these variables are the same, one subject responded, "Well, it's like you have to control both. Both have to be controlled to make sure the experiment goes right" (B). Another subject stated that "they're [both] kept the same in an experiment" (D). It should be noted that both Misconceptions 9.2 and 9.3 are also represented in Tables 5 and 8, respectively. They have been included here because some different subjects made these responses and also to maintain the consistency of the presentation of the research findings obtained from each series of questions.

Quotes like those in the preceding paragraphs indicate that a possible reason for the difficulty experienced with the process of controlling variables involves the everyday meaning subjects associate with the term "control." As discussed by Griffiths (1987), in the non-scientific context, to be controlled means to be regulated, manipulated or modified in some way. However, in the scientific context to be controlled means to be kept constant. This idea parallels an earlier discussion of the "unidentified mismatch" problem that Osborne and Freyberg (1985) claim is a major source of misconceptions in the science classroom. It seems very likely that the conflict between the scientific and everyday meaning of the word "control" frequently fosters the growth of student misconceptions regarding the process of controlling variables, which would account for the prevalence of these misconceptions amongst the sample. An alternative explanation may be that the subjects had never heard of the process of controlling variables, and responded by using the common sense meaning of the word "control."

Misconception 9.4, the idea that controlling variables involves organizing an experiment so it is very easy to do and understand, and Misconception 9.5, the view that an experiment is well controlled if it has few variables, were two other beliefs that represented less than 10% of the sample in each case. The combination of the five misconceptions represented in Table 9 and others that have not been reported in the table, strongly indicates a poor level of competence with the very important process of controlling variables. An appreciation for this process is an essential requirement if students are to become competent in scientific enquiry.

The above finding is consistent with other studies that have assessed student competence in process skills. For example, in 1986 grades 4, 7, and 10 students in British Columbia were involved in a provincial assessment of science. Among other items, the study assessed competency in science process skills. Compared to 1982, the 1986 results showed an overall improvement in student understanding of controlling variables, but students still exhibited difficulty with this process of science.

Overall, only 6 members of the 31 subjects who expressed views about controlling variables, had acceptable conceptions. Many held a very superficial understanding of this process skills area, and the major factor contributing to this lack of understanding is the confusion between the everyday and scientific meanings of the term "control."

When asked **"What were some variables you controlled in your experiment?"**, many subjects responded rather poorly to the question. This result is not surprising in light of their confused conceptions about what controlled variables are. Some subjects simply said they did not know, or could not remember the variables they controlled in their experiments. Most of those who did respond, provided only one or two variables they felt they controlled, and in some cases the independent and dependent variables were included. Although disturbing, this is not surprising given the prevalence of Misconceptions 9.2 and 9.3, and Misconceptions 5.1 and 8.1, respectively. For many of the subjects, controlled variables are the same as independent and dependent variables.

## Importance of Controlling Variables

Misconception 10.1, the idea that controlling variables is very important because it ensures the "right answers" are obtained during an experiment, was a common response to Question 19, **"Why is it important to control variables in an experiment?"**. As seen in Table 10, this misconception was exhibited by over 43% of all respondents, with at least three members from each group making this response. These subjects believed that there is a single, right answer to be found in any scientific investigation, and controlling variables would ensure that it would be found. One subject from group B stated that "if you don't control them [variables], you'll never really see that your results are the real truth," and another suggested that "it is important because it helps your results to be as true as can be. It sort of helps you get the right answer in your project" (D).

Table 10

The Most Common Misconceptions Relating to the Importance of Controlling Variables

| Misconception | Frequency by Group | | | |
|---|---|---|---|---|
| | A | B | C | D |
| 10.1 Controlling variables is very important because it ensures the "right" answers are obtained during an experiment. | 3 | 3 | 3 | 4 |
| 10.2 Controlling variables is important because it gives the experimenter more control over what happens in the experiment. | 0 | 2 | 1 | 2 |
| 10.3 Controlling variables ensures you get the results you want. | 0 | 0 | 0 | 2 |
| Number of subjects with acceptable responses. | 2 | 3 | 2 | 2 |
| Number of subjects with unacceptable responses. | 3 | 2 | 2 | 4 |
| Number of subjects with two or more conflicting responses. | 2 | 3 | 2 | 1 |
| Number of subjects who did not respond, or whose responses could not be classified. | 1 | 0 | 2 | 1 |

The idea that controlling variables is important because it gives the experimenter more control over what goes on in an experiment, was expressed by five members of the sample and is represented as Misconception 10.2 in Table 10. Although this belief was not exhibited by any members of group A, it was given by two members from each of groups B and D and one member from group C. All respondents who held this view felt that controlling variables allows the experimenter to manipulate or alter the results of an experiment. One subject suggested that controlling variables is important because "your experiment will work better, and [will] turn out the way you want it to" (D), and a group B subject said it is important because then "you know what's going to happen. You have the power to change everything and do what you want." Again these ideas indicate the influence of the everyday meaning of the word "control" in the subjects' understanding of the process of controlling variables. The logic that contributed to the formation of Misconception 10.2 is likely very similar to that which contributed to the development of Misconception 9.1. In fact, all five subjects who exhibited Misconception 10.2 also held Misconception 9.1. Table 10 also shows Misconception 10.3, which was an idea held by only two members from group D in the study.

In all, only 9 members of the sample provided an acceptable response to Question 19, and 19 of the remaining 23 subjects gave unacceptable or conflicting responses to the question.

## Inferring Versus Observing

In an attempt to ascertain the subjects' understanding of inferring and observing, they were asked Questions 21 to 24 from the interview protocol. These questions focused on definitions of inferring and observing, the comparison of the two terms, and identifying examples and non-examples of observation statements. Misconceptions were identified by grouping the subjects' ideas under broader belief patterns, and the more common of these are reported in Tables 11 to 13.

### Inferring

When asked **"What is an inference statement?"**, many subjects initially responded that they had never heard of the term before. However, when asked to compare the processes of inferring and observing, most subjects responded freely and yielded a wide range of ideas. The most common misconceptions elicited from this questioning are displayed in Table 11. Six of the 26 subjects who responded to these questions held Misconception 11.1, that inferring is the

Table 11

Most Common Misconceptions Relating to Inferring

| Misconception | Frequency by Group A | B | C | D |
|---|---|---|---|---|
| 11.1 Inferring is the same as observing. | 1 | 2 | 1 | 2 |
| 11.2 Inferences are a person's thoughts about a particular phenomenon. | 2 | 0 | 1 | 3 |
| 11.3 An inference is a guess about the outcome of an event. | 2 | 0 | 1 | 1 |
| 11.4 Inferring is a process of gathering and providing information through research. | 0 | 1 | 1 | 0 |
| Number of subjects with an acceptable response. | 1 | 1 | 2 | 0 |
| Number of subjects with an unacceptable response. | 7 | 6 | 3 | 7 |
| Number of subjects who did not respond, or whose response could not be classified. | 0 | 1 | 3 | 1 |

same as observing. One member from each of groups A and C, and two members from each of groups B and D gave responses corresponding to this misconception. One group A subject claimed that "observing is watching and checking up on something [and] inferring is noticing or observing something while checking up on it. So there is no difference, they're the same," and a group B subject said that "when you're inferring you're observing things, so it's the same thing because they mean exactly the same thing." Another subject stated that inferring and observing are the same ". . . 'cause they look and sound alike" (D). While asking subjects to classify statements as examples or non-examples of observations (to be discussed later), one subject responded that number two is both an observation and an inference ". . . because you can observe the powdery yellow substance and you can infer it" (B).

Nearly one-quarter of the respondents in the sample held Misconception 11.2, that inferences are a person's thoughts about a particular phenomenon. Although no members from group B expressed this view, it was exhibited by two members from group A, one from group C, and three from group D. One subject claimed that ". . . inferring is your thoughts. It represents your thoughts about something" (C), and another felt "inferring is thinking of what might be possible in an experiment" (D).

Misconception 11.3, the belief that an inference is a guess about the outcome of an event, was expressed by at least one member from each group except group B. Representative responses include the following: "Well, to observe is to do the actual test, and to infer you just hypothesize. You guess what will happen" (A); "To infer means to guess or predict what will happen" (D); and "I think inferring means that you just watch a couple of times and you guess what's going to happen afterwards" (A).

Also shown in Table 11 is Misconception 11.4, the idea that inferring is a process of gathering and providing information through research. This view was held by only two members of the sample, one from each of groups B and C. Many other misconceptions were espoused by members of the sample but are not included in Table 11 only because they were not expressed by two or more subjects. The range of responses is depicted in the selected excerpts that follow: ". . . I think inferring is more like you're trying to make it [the experiment] go the way you want it to" (A); an inference is "what you are trying to prove" (A); "Inferring is just thinking things up in your mind; you just make it up" (A); inferring involves "asking questions as to why things were happening" (B); to infer means "to tell somebody something" (B); or "to ask about something or to like go and get more information on something" (C); inferring is "a round-about way of saying something" (D); and "when you infer you're asking what's happening in an experiment" (D). The data collected here clearly suggest that subjects from all four groups have an inadequate understanding of the process of inferring. It is possible that the low competence in this process skills area could be due to its lack of emphasis in science classes. As shown at the bottom of Table 11, 28 subjects (88% of the sample) did not provide acceptable responses to the question asked.

Observing

Question 23 asked, **"What is an observation?"**, and the responses that were classified as misconceptions are presented in Table 12. The idea that observing is seeing or watching what happens, Misconception 12.1, was expressed by at least 50% of the respondents from each group except group C, where 43% of the members exhibited this view. Most of the 16 subjects who held Misconception 12.1 did not recognize the role of the other four senses in observing. An excerpt from one member of each group clearly exemplifies this. One subject claimed that "observing is seeing and taking note of things" (A), while another firmly responded that "observing is really seeing" (B). One group C subject said that only those "things you can see" can be observed, and the response of a subject from group D was that to observe means "to look at; to see what happens after an experiment."

Misconception 12.2, that observations are the actual results of an experiment, is the second most prevalent idea presented in Table 12. One member from group A and at least

Table 12

The Most Common Misconceptions Relating to the Definition of Observing

| Misconception | Frequency by Group A | B | C | D |
|---|---|---|---|---|
| 12.1 Observing is seeing or watching what happens. | 5 | 4 | 3 | 4 |
| 12.2 Observations are the actual results of an experiment. | 1 | 2 | 2 | 3 |
| 12.3 Observing is providing a reason why something happens. | 1 | 0 | 0 | 1 |
| 12.4 An observation is what a person thinks will happen in an experiment. | 0 | 1 | 1 | 0 |
| 12.5 Observations are conclusions about an experiment. | 0 | 1 | 1 | 0 |
| Number of subjects with an acceptable response. | 1 | 2 | 1 | 1 |
| Number of subjects with an unacceptable response. | 7 | 5 | 6 | 7 |
| Number of subjects who did not respond, or whose response could not be classified. | 0 | 1 | 1 | 0 |

two members from each of the other three groups gave responses corresponding to this belief. A group C subject commented that "an observation is your results you get," while another respondent stated that "it's when you're in the lab you observe and that's how you get your results. So it's the same as your results for your project" (D). One group A subject suggested that "an observation is the results you get in an experiment." These and related ideas indicate that some subjects have a restricted view about the process of observing. Although it is true that obtaining results in an experiment involves observing, people whose beliefs do not extend beyond this notion have an inadequate view about the process of observing.

Table 12 shows three other misconceptions that were each exhibited by two members of the sample. Misconception 12.3, the idea that observing is providing a reason why something happens, was exhibited by only one member from each of groups A and D. Misconception 12.4, namely that an observation is what a person thinks will happen in an experiment, and Misconception 12.5, that an observation is a conclusion about an experiment, were each held by one member from each of groups B and C. These two misconceptions were not expressed by any members from groups A and D. In all, only 5 members of the sample correctly defined the term "observation", and 25 of the remaining 27 subjects expressed unacceptable ideas. Many subjects held the restricted view that observing involves only "seeing."

**Identifying Observation Statements**

Table 13 contains a collection of misconceptions arising from responses to Question 24, which asked the subjects to identify examples and non-examples of observations from the following list of six statements:

(1) The burning chemical had a strong, choking smell.

(2) The chemical used in the lab was a yellow, powdery substance.

(3) The solid in the container disappeared because it separated into tiny particles too small to be seen.

(4) When the substances were added together there was a hissing noise.

(5) One of the objects in the lab felt sticky.

(6) The trees near the beach are smaller because of the high winds and salty sea spray.

A very popular idea was Misconception 13.1, that the only statements which can be observations are those which describe the **changes** that have occurred after an experiment is complete. This idea was exhibited by five members from group A, three from group B, two from group C, and six from group D. When one subject from group A was asked if statement five was an example of an observation, the following exchange transpired.

Subject: No, because number five is not really changing between two things.

Table 13

The Most Common Misconceptions Relating to Identifying Observation Statements

| Misconception | Frequency by Group | | | |
|---|---|---|---|---|
| | A | B | C | D |
| 13.1 The only statements which can be observations are those which describe the changes that have occurred after an experiment is complete. | 5 | 3 | 2 | 6 |
| 13.2 An observation involves giving reasons or explanations for what has happened. | 1 | 2 | 1 | 2 |
| 13.3 Only those statements that describe one single, specific object or event are observations. | 2 | 0 | 1 | 1 |
| 13.4 Things noticed by smelling, touching and/or listening are not observations. | 0 | 3 | 0 | 0 |
| Number of subjects who correctly classified all six statements. | 2 | 2 | 3 | 2 |
| Number of subjects who correctly classified four or five statements. | 3 | 4 | 3 | 3 |
| Number of subjects who incorrectly classified at least half of the statements. | 3 | 2 | 2 | 3 |

Interviewer: What do you mean by changing between two things?

Subject: Like nothing happened because it never went from just a plain object to a sticky object.

When deciding if statement number three was an observation, a group B subject responded "that's an observation 'cause you're telling what happened to the solid in the project and it's an observation that they made after the outcome of the project." One subject from group D felt that statement four was an observation only because ". . . it's something that happened after there was something else done to it . . . after it was manipulated." Finally, a subject from group C stated that ". . . number two would not be an observation because that's not what you're looking at as the experiment goes on. That's what's before the experiment." Several other responses were representative of Misconception 13.1, and in general, these subjects felt that only those statements that describe something happening during an experiment could be an observation. In this respect, Misconception 13.1 is similar to Misconception 12.2 discussed previously.

The idea that an observation involves giving reasons or explanations for what has happened, Misconception 13.2, was expressed by one member from each of groups A and C, and two from each of groups B and D. One subject from group A stated that "number six is an observation because it's telling you how come the trees are smaller; it's telling you how or why they are smaller." A member of group C decided that statement six is an observation because "they're telling why they're smaller; because of the high winds and salty sea spray." In responding to statement number three, a subject from group B felt it is an observation ". . . 'cause it tells ya that the solid disappeared into tiny particles too small to be seen. So it tells ya why the ice cubes disappeared." Finally, a member from group D said statement three is an observation because ". . . it's saying why the ice cubes melted and causes you to see why."

Misconception 13.3, that only those statements which describe one single, specific object or event are observations, was exhibited by two members from group A, and one member from each of groups C and D. This misconception was exposed when subjects attempted to classify statement five as an example or non-example of an observation. One subject decided it was not an observation because it did not tell ". . . what object in the lab felt sticky. They felt that it was sticky, but they are not really telling what object they are talking about" (A). The thoughts of a subject from group D are clearly illustrated in the following exchange:

| | |
|---|---|
| Interviewer: | Number five now. |
| Subject: | Ahm no. I guess you'd have to tell what it was you're using. You can't just say "one of the objects" because no one is gonna know what the object was. |
| Interviewer: | So how would you re-word that one to be an observation? |
| Subject: | You'd just say whatever it was. Like you'd put the name there instead of "one of the objects." |

A less frequent but interesting idea is represented as Misconception 13.4 in Table 13. This belief, that things noticed by smelling, touching and/or listening are not observations, was only evident in group B, where three members gave responses coinciding with this view. Excerpts for all three subjects are provided below. After reading the first statement from the list, one subject replied, "Well, I guess observing is looking and you're really smelling that, so I guess it's not an observation" (B). In deciding if statement four is an example of an observation, another subject stated, "I don't think so because it's just telling you that it made a hissing noise. We've done activities and they have made hissing noises and we didn't put them in our observations because it's not really observing" (B). The third subject read statement five and stated ". . . they felt it and they said it felt sticky. So you have to feel it, and that is not observing."

Three other very interesting remarks are worth noting at this point. A subject from group C felt that statement five is an observation, and when asked to justify this decision the response was "because you can **see** the stickiness on the object," and a subject from group D said, "I guess [it's an observation] because you **sees** it being sticky." A subject from group B felt that the first statement is an observation, not because you could smell the fumes, but because you could **see** the smoke and fumes rising from the burning chemical. Probing questions showed that these subjects did not recognize the role of the other senses in the process of observing.

The range and prevalence of misconceptions from subjects' responses to Questions 23 and 24 have been illustrated in Tables 12 and 13. They clearly demonstrate the subjects' lack of understanding and general confusion about the process of observing. Most of the few subjects who did have some understanding of observing, had limited beliefs because they felt that observing could only be done during an actual experiment in the laboratory.

Worthy of note is that only nine subjects from the entire sample were able to correctly classify all six statements as examples or non-examples of observations, and these included two members from each of groups A, B, and D, and three members from group C. Furthermore, at least half of the statements were incorrectly classified by almost one-third of the sample. This evidence strongly suggests a low level of understanding of a very important and basic science process skill.

## Interpreting Data

Questions 25 and 26 respectively asked subjects to provide their ideas about the process of interpreting data and to extract relationships between the variables of two sets of tabulated information. The subjects' responses were quite varied and several misconceptions were identified.

However, most were not exhibited by two or more members of the sample and therefore have not been reported in table form. The following paragraphs discuss the sample's understanding of the process of interpreting data.

When subjects were asked **"What does it mean to interpret data?"**, almost half (48%) of the sample expressed inaccurate and unacceptable views and only 10% of the remainder of the sample gave quality answers. Responses were not characteristic of any particular group and general patterns were difficult to establish. However, belief patterns shared by two or more members of the sample were identified and are presented in Table 14. Misconception 14.1, the belief that interpreting data involves discussing what will happen in an experiment, was expressed by one member from each of groups B and C, and two members from group D. These subjects generally felt that interpreting data is the same as, or similar to hypothesizing. This is illustrated by the comments of one subject who said that "when I think of interpreting results, I think it is kind of a hypothesis; like you are thinking this is what's going to happen, and the results are going to say this" (B). A subject from group D said that people who interpret data ". . . have to guess at what they think could be the reason for something happening," while another member of this group said interpreting data is "like if you mixes two substances, you could interpret or guess at what's gonna happen, like how they're gonna react."

Table 14

The Most Common Misconceptions Relating to the Meaning of Interpreting Data

| Misconception | Frequency by Group | | | |
|---|---|---|---|---|
| | A | B | C | D |
| **Interpreting Data Involves:** | | | | |
| 14.1 discussing what will happen in an experiment. | 0 | 1 | 1 | 2 |
| 14.2 analyzing selected information only. | 1 | 0 | 0 | 1 |
| Number of subjects with an acceptable response. | 5 | 5 | 4 | 3 |
| Number of subjects with an unacceptable response. | 3 | 3 | 3 | 4 |
| Number of subjects who did not respond, or whose response could not be classified. | 0 | 0 | 1 | 1 |

Misconception 14.2, namely that interpreting data involves analyzing selected information only, was expressed only by one member from each of groups A and D. As the subject from group A replied, "you have to know what you are looking for in your data" so you can direct your attention to these specific areas. The subject from group D suggested that interpreting data involves selecting only the information ". . . that isn't particularly understandable and . . . turn[ing] it into something that you do understand."

Other ideas held by the sample about interpreting data which are not provided in Table 14 are exemplified in the following excerpts: "It means proving the results to a definite point that you know is true" (A); "it's like an observation. You're telling what you did and what you saw happen after the project was done" (B); "It's like when you get your results, to know how these results came about" (C); and, "It means having different results and having a different way of getting the results" (D). In all, 48% of the sample had inaccurate views about the process of interpreting data.

Item 26 in the guide involved presenting the subject with two sets of data in tabular form (see pages 168 and 169 of Appendix A for Tables 1 and 2) and asking the subject to interpret them. Twenty-three of the 31 respondents were able to easily interpret the data. Seven members from group A, six from groups B and D, and four from group C effectively made statements about the relationships between variables in each table. Generally, most members of the sample were quite able to interpret the data presented, even though almost half of them had inaccurate conceptions about its meaning. This suggests that the ability of subjects to perform tasks involving process skills may not depend on their conceptions of the process names themselves.

## Predicting

The last series of questions in the interview guide pursued the subjects' views about the process of predicting. Questions 27 through 32 asked for a definition of the term "prediction", for a comparison of the processes of predicting and hypothesizing, and for actual predictions both within and beyond the bounds of a given set of data. The most popular misconceptions are presented in Tables 15 to 17. A general discussion of the research findings follows.

### Definition of Prediction

When subjects were asked **"What is a prediction?"**, responses were very consistent for all four groups. Table 15 contains those misconceptions that were exhibited by two or more members of the sample. Misconception 15.1, the belief that a prediction is a guess about the outcome of an experiment, was held by 70% of the respondents in the sample. Specifically, seven members from group A, four from

Table 15

The Most Common Misconceptions Relating to the Definition of Predicting

| Misconception | Frequency by Group | | | |
|---|---|---|---|---|
| | A | B | C | D |
| 15.1 A prediction is a guess about the outcome of an experiment. | 7 | 4 | 4 | 6 |
| 15.2 A prediction is the result or outcome of an experiment. | 0 | 1 | 1 | 1 |
| Number of subjects with an acceptable response. | 0 | 2 | 0 | 1 |
| Number of subjects with an unacceptable response. | 8 | 6 | 6 | 6 |
| Number of subjects who did not respond, or whose response could not be classified. | 0 | 0 | 2 | 1 |

each of groups B and C, and six from group D believed that a prediction is a guess. The response of one subject from group C typifies the beliefs of all members who held Misconception 15.1. This subject claimed that a prediction is "a guess at what's going to happen in your project" (D).

Misconception 15.2, the idea that a prediction is the outcome or the result of an experiment, was expressed only by one member from each of groups B, C, and D. One subject stated that a prediction is "what the outcome of your project is. You know, it's what happens as the project is done" (D). Another subject suggested that "it's what happens or what will happen in an experiment" (B). Worth noting is that the definition of predicting endorsed by Griffiths (1987) as "forecasting future events on the basis of observed regularities in past events" (p. 20) was only reflected in the responses of three members of the sample. Meanwhile, 26 subjects gave unacceptable responses and 3 others could not respond, or gave responses that could not be classified.

## Comparison of Predicting and Hypothesizing

When subjects were asked Question 28, **"Is there a difference between a prediction and a hypothesis, or are they basically the same?"**, 22 of the 32 subjects exhibited ideas corresponding to Misconception 16.1. As reported in Table 16, all eight members from group A, six from group B,

Table 16

The Most Common Misconceptions Relating to the Comparison of Predicting and Hypothesizing

| Misconception | Frequency by Group | | | |
|---|---|---|---|---|
| | A | B | C | D |
| 16.1 A prediction is the same as a hypothesis. | 8 | 6 | 4 | 4 |
| 16.2 A prediction is less certain than a hypothesis because it is not based on any information. | 0 | 1 | 1 | 2 |
| Number of subjects with an acceptable response. | 0 | 0 | 0 | 0 |
| Number of subjects with an unacceptable response. | 8 | 8 | 6 | 8 |
| Number of subjects who did not respond, or whose response could not be classified. | 0 | 0 | 2 | 0 |

and four from each of groups C and D expressed the view that a prediction is the same as a hypothesis. Most of these subjects reasoned that predicting and hypothesizing are both guesses about the outcome of an experiment. This is illustrated in the following exchange with a subject from group A:

| | |
|---|---|
| Interviewer: | What is a prediction? |
| Subject: | A prediction can be similar to a hypothesis because it's a guess basically; an educated guess. |
| Interviewer: | What is the difference between a prediction and a hypothesis? |
| Subject: | I don't think there is much of a difference, if any. |
| Interviewer: | So how are they the same? |
| Subject: | Well in a hypothesis you are guessing what will happen in your experiment. A prediction you can be guessing at something too. So I'd say they are the same because they are guesses. |

It is evident that the majority of the subjects believe that the processes of hypothesizing and predicting are identical. This is not only illustrated by Misconception 16.1, but also by Misconception 1.1 in Table 1 and Misconception 15.1 in Table 15.

Eight of the 32 subjects felt that a prediction is not the same as a hypothesis, and the reason given by four of these is characterized by Misconception 16.2, namely that a prediction is less certain than a hypothesis because it is not based on any information. One subject from group B claimed that a hypothesis is based on many scientific facts

". . . but a prediction you're just not really basing it on facts or anything. You're just guessing at something." One group D subject said "a hypothesis is based on scientific findings and a prediction is kind of like what you think is going to be the end result," and another said "a hypothesis is based on all the information that you have so far, but a prediction is just what you believe will happen" (D).

One subject from group C who felt hypothesizing and predicting are different, had a totally opposite view to that represented by Misconception 16.2. This subject said "for a hypothesis you wouldn't have facts or anything to go on from before. But a prediction can use facts [whereas] a hypothesis you just totally get it out of your own mind" (C). A member from group D said the two processes are different because "a hypothesis is a question and a prediction . . . would be the answer to your hypothesis." The remaining two subjects from the eight who felt a prediction and a hypothesis are different, could not provide reasons for their beliefs, even after a series of probing questions.

Worthy of note is that Misconception 16.1 seems to indicate that groups A and B subjects have less understanding of the processes of hypothesizing and predicting than members of the other two groups. However, as shown at the bottom of Table 16, all respondents gave unacceptable responses when asked to compare hypothesizing and predicting.

**Interpolating Versus Extrapolating**

In an attempt to determine their ability to interpolate and extrapolate, subjects were asked Questions 29 to 32 from the guide. These questions related to Table 1 of Appendix A (see page 168). Subjects were presented with Table 1 showing the relationship between "amount of water" and "growth of bean plants." Data for five plants were displayed. Plant 1 was given 5 ml of water each day for a period of two weeks. Plants 2, 3, 4, and 5, respectively, received 10, 15, 20, and 25 ml of water each day. The height of each plant after two weeks ranged from a low of 4 cm for plant 1, to a high of 35 cm for plant 5.

After presenting them with Table 1, subjects were told to assume there was a sixth plant in the experiment. They were then asked to use this data to interpolate the height of the plant after two weeks, if it had been given 18 ml of water per day. Furthermore, they were asked to extrapolate the plant's height after two weeks if it had been given 35 ml of water each day. Finally, the subjects were asked to justify which of the two predictions they could be most certain about. All but two subjects adequately and reasonably predicted the plant's height would be 28 to 30 cm if given 18 ml of water each day, and 38 to 44 cm if the daily amount of water was 35 ml. Subjects from all four groups were very consistent with their interpolations and typically gave an answer represented by one single number. However, when extrapolating, 29 of the subjects gave less focused answers represented by a range between two numbers (for example, 39 to 43 cm). A possible reason for this uncertainty is the recognition of the dangers involved with predicting beyond the available data. As a result, subjects were apprehensive about extrapolating and felt more comfortable giving more general and less specific answers. Overall, subjects displayed an adequate ability to interpolate and extrapolate.

As shown by Misconception 17.1 in Table 17, only three members of the sample believed that extrapolating is just as safe as interpolating. The member from group B said that he was "basically just as certain about both [interpolating and extrapolating], although the second one it seems like you can do more with it kind of to a certain degree. But you're basically just as certain about both." The subject from group C said that "I'm just as certain about both [because] in both cases you have other information there to help you." The only other misconception identified from subject responses to Question 32 is not represented in Table 17 because it was expressed only by a single subject from group D. As indicated in the following exchange, this subject felt that extrapolating is safer than interpolating but could not adequately justify her position when asked:

Interviewer: Now, which of these two predictions are you most certain about, or are you just as certain about both?

Subject: The second one.

Table 17

The Most Common Misconceptions Relating to the Comparison of Interpolating and Extrapolating

| Misconception | Frequency by Group A | B | C | D |
|---|---|---|---|---|
| 17.1 Interpolating is just as safe as extrapolating. | 1 | 1 | 1 | 0 |
| Number of subjects with an acceptable response. | 7 | 7 | 7 | 7 |
| Number of subjects with an unacceptable response. | 1 | 1 | 1 | 1 |
| Number of subjects who did not respond, or whose response could not be classified. | 0 | 0 | 0 | 0 |

Interviewer: The one with 35 ml of water?

Subject: Yeah.

Interviewer: So why are you more certain about that one?

Subject: Because that one has more water and obviously if it's got more water it's gonna grow.

In general, all but four subjects quite adequately performed interpolations and extrapolations, even though many of them had false views about the process of predicting.

## Summary

This chapter has presented the research findings obtained from subject responses to 32 questions regarding selected processes of science. Analysis of the findings involved displaying misconceptions for specific processes in tabular form to indicate the range and prevalence of these ideas amongst the sample. In many cases actual subject quotes or exchanges from interviewing sessions were presented to facilitate the presentation of data regarding the sample's competence with the processes of science.

In all, a total of 58 different misconceptions were identified, and some of these ideas were very common, while others were expressed by only two subjects. However, results did indicate that all four groups of subjects, regardless of level of interest and participation in science fairs, have a poor understanding of many of the fundamental aspects of the processes of science. Even those who seemed to have a good understanding of the processes often exhibited a superficial understanding that could potentially interfere with attainment of other skills.

Chapter 5 summarizes the findings of the study, identifies some educational implications, and provides recommendations for further work.

# CHAPTER 5

# SUMMARY, EDUCATIONAL IMPLICATIONS, AND RECOMMENDATIONS

## Overview of the Chapter

This chapter summarizes the research findings obtained from the study, discusses the educational implications of the research and suggests recommendations for further research endeavors.

## Summary of the Study

The intent of this study was to ascertain a group of secondary students' understanding of selected science process skills. Specifically, efforts were taken to identify common misconceptions students held about the processes of planning an experiment, hypothesizing, identifying and controlling variables, inferring, observing, interpreting data, and predicting. The design of the study involved identifying four groups of students differentiated on the basis of their level of interest and participation in science fairs. These groups included the regional "science fair winners" (group A), the regional "science fair non-winners" (group B), the "science fair participants" at a school science fair (group C), and "science fair non-participants" (group D). Potential subjects for each group were identified and eight of these were randomly selected to represent the group. Subjects were interviewed using a semi-structured interview protocol and each session was tape-recorded and later transcribed for further analysis. Careful examination of the transcripts led to the development of conceptual inventories which contained the subjects' conceptions relative to each process skill investigated. Scrutiny of the inventories resulted in the identification of many misconceptions, which are discussed below.

Overall, the research findings suggest that a large number of our secondary school students do not have scientifically accepted views about the processes of science. In many cases, the subjects' responses indicated that their conceptions of specific process skills are largely influenced by the common meanings of familiar words like "independent", "dependent", and "control." The following is an overview of the research findings relative to each process skill explored:

(i) **Planning an Experiment:** Although questioning revealed no misconceptions about this process skill, a wide range and sophistication of responses were expressed. However, only a small proportion of the sample held elaborate conceptions about this area. Some subjects recognized the need to select essential materials and gather them together well in advance of conducting an experiment. Others felt it was necessary to consult with experts or to research the topic during the early planning stage. Members of groups A and B responded more quickly to questions about planning an experiment, while members of groups C and D often required the questions to be repeated. Despite this, responses were not characteristic of any particular group. Many subjects from all groups had limited views about planning an experiment.

(ii) **Definition of Hypothesis:** Those subjects who had participated in the regional science fair (groups A and B) were very consistent in their views about the nature of a hypothesis. More than 62% of the members of these two groups believed that a hypothesis is a guess about the outcome of an experiment. The participants at school science fairs (group C) and the science fair non-participants (group D) also held this belief, but it was expressed by only 25% of the members from each group. However, members of groups C and D had a much greater range of responses than members of groups A and B. In fact, many of the ideas expressed by groups C and D could not be represented in table form because they were given by only one member each. None of the 32 members of the sample gave an acceptable definition of the term "hypothesis."

(iii) **Identifying Hypotheses Statements:** When asked to classify six statements as examples and non-examples of hypotheses, a range of subject understanding was identified. Only two subjects (one from each of groups A and B) correctly classified all six statements, while more than 60% of the sample (including all eight members of group D) classified at least half of them incorrectly. Subjects from all four groups expressed a variety of ideas that were judged to be inconsistent with the scientific view. The most popular misconception held by subjects in all groups except group D, was the belief that all statements of uncertainty are hypotheses. Surprisingly, the most common misconception for group D subjects was the idea that hypotheses are statements of fact. Exactly half of the members of group D held this belief. In all, subjects had a very inadequate understanding about the process of hypothesizing.

(iv) **Definition of Independent Variable:** Less than one-third of the sample gave an acceptable response for the meaning of the term "independent variable", with 7 of the 10 correct responses coming from members of groups A and B. Forty percent of respondents believed that an independent variable is one that is separate or independent from the rest of an experiment, and has no effect on the results. This belief was particularly prevalent amongst group D subjects where 75% of the members expressed it. A possible reason for this belief, one supported by related research, is the confusion presented by the language. Another popular view was that an independent variable is one an experimenter cannot change or manipulate in any way; it regulates or controls itself. Nine members of the sample expressed views consistent with this idea. While individuals from group A expressed few misconceptions that were consistent with the responses of other members of the sample, only three of them had an acceptable understanding of the term "independent variable." Four members from group B, two from group C, and only one from group D expressed acceptable views about this topic.

(v) **The Number of Independent Variables in an Experiment:** Six members of the sample felt that the more complicated an experiment is, the greater the number of independent variables it will have. Another misconception was the belief that ideally there should be no independent variables in an experiment. This idea was exhibited by only one member from each of groups A, B, and C. Three-quarters of the sample stated that there is no set number of independent variables in an experiment. Many of these felt that in order to get the results needed, the experimenter can change the number of independent variables as desired. Only 46% of the sample gave acceptable responses about the actual number of independent variables there should be in an experiment.

(vi) **Comparison of Independent and Controlled Variables:** Eleven members of the sample felt that an independent variable is the same as a controlled variable. This idea was expressed by one member from group A, three from each of groups B and C, and four from group D. The reason provided by virtually all subjects was that the experimenter can control both types of variables, where "control" meant to manipulate as desired. The second most popular idea was that the two variables are different because an independent variable cannot be manipulated or "controlled" like a controlled variable can. This view was expressed by at least one member from each group. Overall, only 11 members from the entire sample were able to adequately compare the two kinds of variables.

(vii) **Definition of Dependent Variable:** Subjects from all four groups espoused a range of ideas about the term "dependent variable." Misconceptions identified were often expressed by only three or four members of the sample. The most popular idea was that a dependent variable is the opposite of an independent variable. This view was held by five members of the sample, and four of these were from groups C and D. Three members from each of groups A and B, two from group C, and one from group D held acceptable views about dependent variables. Over 70% of the sample held views about dependent variables that were judged to be inconsistent with the scientifically accepted view.

(viii) **The Number of Dependent Variables in an Experiment:** Only 11 members of the sample held an acceptable view about the actual number of dependent variables there should be in an experiment. However, only some of these demonstrated understanding of why they gave the answers they did. Four of the five members from group D who said that there is no set number of dependent variables in an experiment, felt that the number for a given experiment could change depending on what the experimenter wanted to prove. The two most common misconceptions were the ideas that more complicated experiments will have a greater number of dependent variables, and an experiment can have only one dependent variable. Both of these ideas were expressed by seven members of the sample and at least one member from each group gave responses corresponding to the two ideas. Almost two-thirds of the sample displayed a poor understanding about this area, and the source of confusion appeared to be rooted in the everyday meaning associated with the term "dependent." For example, many subjects felt that dependent variables are those that are "dependent" on the rest of the experiment. They often could not respond beyond this level.

(ix) **Comparison of Dependent and Controlled Variables:** When subjects were asked to compare dependent and controlled variables, 15 of the 27 subjects who responded gave acceptable answers. Eleven members gave unacceptable responses, while five could not respond to the question. Members of group B expressed the most difficulty with the question, as only two of them gave acceptable responses. The most common misconception identified was that a dependent variable is the same as a controlled variable. This belief was held by one member from group A and two from each of groups B, C, and D. These subjects felt that the experimenter has "control" over both types of variables in the sense that he or she can change them as desired. The only other misconception, the idea that a dependent variable is the opposite of a controlled variable, was expressed by only two members from group B.

**(x) Definition of Controlled Variable:** One of the most prevalent misconceptions in the entire study was expressed by subjects when they were asked what a controlled variable is. Seven members from group A, five from group B, four from group C, and six from group D felt that controlled variables are those whose effect on an experiment are determined by the experimenter. The confusion experienced by these subjects appeared to originate from the word "control" and the everyday ideas associated with it. They reasoned that a controlled variable is any variable that the experimenter could change or manipulate as he or she desired. Another common idea was that a controlled variable is the same as an independent variable. This belief was held by three members from group B, two from group C, and four from group D, and the reason given by all but one of them was that the experimenter could change both variables when it was deemed necessary. Overall, the subjects had a very poor understanding about controlled variables. Only 6 members of the sample provided acceptable responses to the question asked, and 26 had unacceptable or conflicting views.

**(xi) The Importance of Controlling Variables:** When asked about the importance of controlling variables, 13 of the 30 subjects who responded felt that it would ensure that the experimenter would get the "right" result or outcome from the experiment. Subjects not only felt that there is one set, right answer for scientific experiments, but felt that this answer could be obtained by changing (controlling) the variables. Five members of the sample said that controlling variables gives the experimenter more control over what goes on in the experiment, and two members from group D felt that by controlling variables you get the exact results you want. The findings indicate that our secondary school students have very inadequate conceptions about an important science process skill. Specifically, many of them apparently do not understand what controlled variables are, and also do not appreciate the importance of controlling variables in an experiment. This is a fundamental skill to be mastered by all science students, and has substantial implications for general education as well. In all, only nine members of the sample provided acceptable views about the importance of controlling variables.

(xii) **Inferring:** Subjects displayed substantial confusion about the process of inferring, and only four members of the sample exhibited acceptable responses about this process. One misconception was that inferring is the same as observing. This idea was held by one member from each of groups A and C, and two members from each of groups B and D. Another belief was that inferences are a person's thoughts about a particular phenomenon. This idea was not evident in group B, but represented 25% of the respondents from group A, 20% of group C, and 43% of group D respondents. Four members of the sample, including two from group A and one from each of groups C and D, felt that inferring is guessing at the outcome of an experiment. In all, 28 members of the sample expressed a great deal of difficulty with this topic.

(xiii) **Definition of Observing:** In attempting to define the term "observing", members of the sample gave a wide range of responses. Sixteen members of the sample felt that observing is seeing or watching what happens in an experiment. Forty-three percent of the subjects in group C, and at least half of the members of each of the other three groups held this view. These subjects failed to recognize the role of the other four senses in observing. Another idea, that observations are the actual results of an experiment, was held by eight members of the sample. One member from group A and at least two members from each of the other three groups supported this view. Several other ideas were identified but most of them were not very common. In all, only five members from the entire sample had an acceptable understanding of this process skills area.

(xiv) **Identifying Observation Statements:** When asked to classify six statements as examples or non-examples of observations, subjects exhibited an array of ideas, many of which were very limited in scope. The most prevalent idea, that the only statements which can be observations are those which describe the changes that have occurred after an experiment is complete, was expressed by over half of those who responded to the statements. Five members from group A, three from group B, two from group C, and six from group D exhibited views corresponding to this idea. These subjects would not consider a statement to be an observation if it just simply described something. In order for it to be an observation, it had to describe the changes in an object after an experiment. Six members of the sample, including one from each of groups A and C and two from each of groups B and D, felt that observations are statements which provide explanations for what has happened.

Another idea was the belief that observation statements can only describe one specific object or event. This was expressed by two members from group A and one from each of groups C and D. Finally, three members of group B claimed that things noticed by smelling, touching, and/or listening are not observations. Overall, two members from each of groups A, B, and D, and three members from group C correctly classified all six statements as examples and non-examples of observations. Meanwhile, at least half of the statements were incorrectly classified by 30% of the sample. This included three members from each of groups A and D, and two from each of groups B and C.

(xv) **Definition of Interpreting Data:** Subjects had quite a range of ideas about the process of interpreting data. Seventeen of the respondents gave an acceptable response about this process. Each subject felt that interpreting involved analyzing the data to identify relationships, and then making statements based on these. Forty-eight percent of the sample gave unacceptable responses, or responses that could not be classified. Only two misconceptions were identified which were expressed by two or more members of the sample. First, one member from each of groups B and C, and two members from group D felt that interpreting data involves discussing what will happen in an experiment. Second, one member from each of groups A and D felt that it involved analyzing selected information only. Despite the fact that almost half of the sample had inadequate conceptions about the meaning of the term "interpreting data", subjects generally performed quite well when asked to interpret two sets of tabulated data. This suggests that the subjects' conceptions of the process skills and how well they perform them may not be entirely dependent on each other.

(xvi) **Definition of Predicting:** A very prevalent idea here was that a prediction is a guess about the outcome of an experiment. This misconception was common among 70% of the respondents. Seven members from group A, four from each of groups B and C, and six from group D expressed this belief. Another idea, that a prediction is the result or outcome of an experiment, was held by one member from each of groups B, C, and D. Only three members of the entire sample had an accurate perception about the process of predicting.

(xvii) **Comparison of Predicting and Hypothesizing:** At least half of the members from each of the four groups felt that a prediction is the same as a hypothesis. These subjects felt that both were educated guesses about the outcome of an experiment. In all, 22 members of the sample held this idea. Four other members of the sample, one from each of groups B and C and two from group D, felt that a prediction is different than a hypothesis because it is less certain. These subjects claimed that a prediction is a guess from the top of your head, while a hypothesis is a guess based on some prior knowledge. No one from the sample adequately compared the two processes of predicting and hypothesizing.

(xviii) **Interpolating Versus Extrapolating:** In efforts to ascertain the subjects' understanding of the processes of interpolation and extrapolation, they were asked to predict within and beyond a set of data presented in table form. Subjects were then asked to justify the prediction they felt more certain about. Virtually all members of the sample adequately predicted within and beyond the data, and all but four subjects recognized the danger of predicting beyond available data. The only misconception common to two or more subjects was that extrapolating is just as safe as interpolating. This idea was expressed by one member from each of groups A, B, and C. Seven members from each group adequately compared the processes of interpolating and extrapolating.

In view of the evidence revealed in the present study, it is clear that secondary school students have inadequate and unacceptable conceptions about important science process skills. As demonstrated by the range and prevalence of misconceptions identified, members of all groups provided inaccurate responses to many of the questions asked. Subjects with the greatest amount of experience in science fairs (groups A and B), did tend to respond more quickly to questions, and sometimes provided more detailed answers. However, no significant differences in process skills understanding were identified amongst the four groups.

Subjects who did seem to understand particular process skills often had only superficial conceptions about them. This was best illustrated in the subjects' responses about the process of controlling variables. Some of them appeared to be very competent in this area, by suggesting that controlling variables involves ensuring that selected variables are held constant during an experiment. But further questioning of these subjects revealed that their deeper belief patterns correspond to the view that controlling variables means that the experimenter decides how the variables will affect the results of an experiment. They felt that the experimenter manipulates the variables as he or she wishes to get the outcome desired.

It is felt that the results of this study reflect the amount of emphasis placed on process skills in science classes. It should not be interpreted as a reflection of the ability of students to acquire these skills. Since many studies have shown that process skills can be effectively taught, the present results probably indicate that not enough emphasis is directed towards these skills.

Thus, the findings of this study may be used as a measure of the priority placed on the process skills in science classes. It may also help teachers become more fully aware of the range of ideas students hold about important process skills, and it is hoped that this can help them become more successful in developing these process skills in students. In this context, it is felt that these findings may indeed have some important educational implications for all science teachers and curriculum developers, especially those who are genuinely devoted to emphasizing the processes of science.

## Educational Implications

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

1. More emphasis must be placed on the processes of science in our secondary schools. Teachers must promote these skills at all grade levels, but particularly in grades 7 to 9 where the curriculum is more flexible. Far too many students know too little about important process skills. Science process skills cannot be ignored, and it must not be assumed that students will acquire them autonomously. A deliberate effort must be expended to facilitate the acquisition of these skills.

2. Many of the misconceptions identified in the study appear to emanate from the confusion subjects

experienced with the everyday and scientific meanings of terms. Most obvious of these involved the terms "independent variable", "dependent variable", "controlled variable", and "observing." Therefore, teachers and curriculum developers must be particularly careful when using language that has an everyday meaning which differs from the scientific meaning of such terms. Furthermore, science teachers must ensure that deliberate efforts are taken to promote the distinction between scientific and common meanings of terms like those listed above. Otherwise, the formation of misconceptions will be nurtured, and the development of an acceptable appreciation for the processes of science will be jeopardized.

3. Teachers must not assume that students do not hold conceptions about process skills prior to exploring them in their science classes. They must also recognize that any preconceptions which do exist, will often be inconsistent with scientific consensus. Thus, it is essential that teachers strive to ascertain the existence of any misconceptions, so that they can then teach the students about process skills in the context of what they already know.

4. The research findings indicate that those students who are exposed to the processes of science, probably learn them by rote memory. This would explain why the

subjects in the study expressed so much confusion about these skills. When questioned about specific process skills, many of the subjects, especially those who participated in science fairs (groups A, B, and C), claimed that they used to know these skills but they can no longer recall them. Teachers should promote the meaningful learning of process skills rather than encourage students to acquire them through rote memorization. This can be accomplished by ensuring that students experience substantial hands-on exploration of scientific phenomena in settings which encourage and require the use of these skills. It should be recognized that, when properly developed and implemented, science fairs can be an ideal avenue for students to practice and refine their skills so that they become more meaningful to them.

5. The results of the study indicate that the students' understanding of the process skills and their ability to perform them, are not necessarily dependent on each other. Some students may be quite competent in performing the science process skills, but may not know what they are or be able to explain them, and vice versa. Therefore, it is important that teachers and curriculum developers acknowledge the need for specific learning strategies that will foster competence in both aspects of the process skills, the ability to

understand them and to perform them.

6. It became apparent from the study that the textbooks that students use are a source of misconceptions in the area of process skills. Many student texts and other educational materials provide inconsistent and often inaccurate definitions of these process skills. For example, high school science texts define the term "hypothesis" as a guess or educated guess about the outcome of an experiment. Since they encourage the formation of misconceptions amongst students, curriculum developers and textbook writers must attempt to eliminate these sources of misconceptions by ensuring consistency and accuracy in the discussion of the processes of science in educational material. Teachers must have accurate materials to work with if misconceptions are to be avoided.

7. Many educators have suggested that new topics would be most effectively learned if the students' preconceptions about these topics could be identified prior to instruction. They argue that teachers should have a dual role of investigator/facilitator, where the first role is to investigate students' preconceptions. The interview technique used in the current study could possibly be used to effectively identify students' views on each process skill prior to covering it in

class. Alternatively, a more practical approach would be to use the findings in the present study as a foundation for the development of a valid and reliable paper-and-pencil diagnostic instrument that could be easily administered and quickly interpreted by science teachers to establish their students' preconceptions about a particular process skills area. Only then will instruction in this important area have its maximum intended effect.

## Recommendations for Further Research

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

1. More far-reaching research needs to be conducted to ascertain student competence in process skills at all levels of education. Representative samples of students from all grade levels need to be interviewed to determine how well the science process skills are understood and performed.

2. Extensive research is required to establish the state of science education in our schools. To what degree are science process skills emphasized in science courses?

3. The results of the current study could serve as a pilot study for other researchers who plan to do much more extensive research. For example, the current results could be used to develop a two-tier multiple choice instrument (Treagust, 1986) which could then be used to explore much larger samples of students to more reliably ascertain the prevalence of misconceptions amongst different groups.

4. Studies need to be performed to explore the relationship between students' academic ability and their level of competence with science process skills.

5. More research could be done to further explore the proposed relationship between students' cognitive level of operation and their ability to learn and perform science process skills.

6. Since the present study, especially in terms of its methodology, is an exploratory one in an area that had not been studied until now, confirmatory studies should be performed that could improve the generalizability of the findings of this research, and also add to a body of information that is presently quite small.

7. More studies need to be done to establish the relationship between student understanding of the process

skills and their ability to perform them. For students holding misconceptions about the processes, a series of studies could be conducted to determine how well they perform the skills in a hands-on situation.

8. Studies need to be conducted to establish effective teaching strategies for science process skills. These strategies could minimize the formation of students' misconceptions in this area, and therefore improve upon the current state of science education in our schools.

## 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 in this area of misconceptions-related research.

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# Appendix A

## Interview Guides and Accompanying Data Sheets

**Interview Guide A**

**For Groups A, B, and C of the Study**

**I) General Questions**

1. What is the title of your project?
2. Where did you get the idea for the project?
3. Tell me a little more about your project.

**II) Questions Regarding Science Process Skills**

**EXPERIMENTING**

*Planning an Experiment:*

4. How did you **plan** your experiment?
   i. What kinds of things did you consider before you started doing your experiment?
   ii. What steps did you go through to get your experiment in place?

**HYPOTHESIZING**

*Defining Hypothesis:*

5. What is a **hypothesis**?
6. What hypothesis did you investigate in your experiment?
   i. What did you expect to be the outcome of your experiment?

*Identifying Hypotheses:*

7. Tell me if each of the following statements is an example or a non-example of a hypothesis, and give reasons for your answers.

## IDENTIFYING AND CONTROLLING VARIABLES

*Listing Variables:*

8. Other students I talked to said how important it is to identify the variables in their experiment. What were some **variables or factors** you felt could have affected the results of your experiment?

*Independent Variable:*

9. What is an **independent variable**?

   i. What is a **manipulated variable**?

10. How many independent (manipulated) variables did you have in your experiment? Can you name one?

    i. Can you tell me a factor or variable you changed while doing your experiment?

11. How many independent (manipulated) variables should there be in any experiment, or is there a set number?

12. Is an independent variable the same as a controlled variable, or are they different? Explain.

*Dependent Variable:*

13. What is a **dependent variable**?

    i. What is a **responding variable**?

14. How many dependent (responding) variables did you have in your experiment? Can you name one?

    i. Can you tell me a factor or variable you noticed a change in as you conducted your experiment?

15. How many dependent (responding) variables should there be in an experiment, or is there a set number?

16. Is a dependent variable the same as a controlled variable, or are they different? Explain.

*Controlling Variables:*

17. What is a **controlled variable**?

18. What does it mean to **control variables** in an experiment?

    i. When students talk about how they controlled certain variables in their experiments, what do they mean?

19. What were some variables you controlled in your experiment?

    i. What variables or factors did you try to keep constant throughout your experiment?

20. Why is it important to control variables in an experiment?

**INFERRING VERSUS OBSERVING**

*Inferring:*

21. What is an **inference statement**? Can you give me an example of an inference arising from your experiment?

22. Is there a difference between inferring and observing? If so, how would you explain this difference to someone who doesn't know these terms?

*Observing:*

23. What is an **observation**?

24. From the following list, identify those statements that you feel are **observations** and give reasons for your answers.

**INTERPRETING DATA**

*Interpreting Data:*

25. Students in science fairs also talk about interpreting the data of their experiments. What does it mean to **interpret data**?

26. Examine the data in Tables 1 and 2. What conclusion can you make from Table 1? What about Table 2?

**PREDICTING**

*Defining Prediction:*

27. What is a **prediction**?

28. Is there a difference between a prediction and a hypothesis, or are they the same? Explain.

*Interpolating Versus Extrapolating:*

29. A student did a science fair project on plant growth. The results of her experiment are shown here in Table 1. Assume there was a sixth plant here. What would be its height after 2 weeks if it received 18 ml of water per day?

30. How certain are you of that?

31. What would be the height of the sixth plant after 2 weeks if it received 35 ml of water per day?

32. What prediction are you most certain about, or can you be just as certain about both? Explain.

**Interview Guide B**

**For Group D in the study**

**I) General Questions**

1. Have you ever participated in a science fair? (If yes), What was your project about?

2. (If no), Have you ever participated in an experiment in science?

3. (If yes), What was it about?

**II) Questions Regarding Science Process Skills**

**EXPERIMENTING**

*Planning an Experiment:*

**Let's suppose you were going to do an experiment to see how "*different amounts of light affect the growth of bean plants*."**

4. How would you **plan** this experiment?

   i. What kinds of things would you consider before you started doing this experiment?

   ii. What steps would you go through to get this experiment in place before carrying it out?

**HYPOTHESIZING**

*Defining Hypothesis:*

5. One of the first things people do when they experiment is to develop a hypothesis. What is a **hypothesis**?

6. What would be a hypothesis for the above experiment?

   i. What do you expect to be the outcome of the experiment?

*Identifying Hypotheses:*

7. Tell me if each of the following statements is an example or a non-example of a hypothesis, and give reasons for your answers.

**IDENTIFYING AND CONTROLLING VARIABLES**

*Listing Variables:*

8. Other students I talked to discussed the importance of identifying the variables in their experiments. What are some **variables or factors** you feel could affect the results of this experiment?

*Independent Variable:*

9. What is an **independent variable**?

   i. What is a **manipulated variable**?

10. How many independent (manipulated) variables would there be in the above experiment? Can you name one?

    i. Can you tell me a factor or variable you would change while doing this experiment?

11. How many independent (manipulated) variables should there be in any experiment, or is there a set number?

12. Is an independent variable the same as a controlled variable, or are they different? Explain.

*Dependent Variable:*

13. What is a **dependent variable**?

    i. What is a **responding variable**?

14. How many dependent (responding) variables did you have in your experiment? Can you name one?

    i. Can you tell me a factor or variable you might notice a change in if you conducted this experiment?

15. How many dependent (responding) variables should there be in an experiment, or is there a set number?

16. Is a dependent variable the same as a controlled variable, or are they different? Explain.

*Controlling Variables:*

17. What is a **controlled variable?**

18. In carrying out the above experiment you would have to be concerned about controlling variables. What does it mean to <u>control variables</u> in an experiment?

    i. When students talk bout how they controlled certain variables in their experiments, what do they mean?

19. What are some variables you would control while doing this experiment?

    i. What variables or factors would you try to keep constant throughout the experiment?

20. Why is it important to control variables in an experiment?

**INFERRING VERSUS OBSERVING**

*Inferring:*

21. What is an <u>inference statement</u>? Can you give me an example of an inference that could arise from the above experiment?

22. Is there a difference between inferring and observing? If so, how would you explain this difference to someone who doesn't know these terms?

*Observing:*

23. What is an **observation?**

24. From the following list, identify those statements that you feel are <u>observations</u> and give reasons for your answers.

## INTERPRETING DATA

*Interpreting Data:*

25. Whenever someone does an investigation, he or she has to interpret data. What does it mean to **interpret data**?

26. Examine the data in Tables 1 and 2. What conclusion can you make from Table 1? What about Table 2?

## PREDICTING

*Defining Prediction:*

27. What is a **prediction**?

28. Is there a difference between a prediction and a hypothesis, or are they the same? Explain.

*Interpolating Versus Extrapolating:*

29. A student did a science fair project on plant growth. The results of her experiment are shown here in Table 1. Assume there was a sixth plant here. What would be its height after 2 weeks if it received 18 ml of water per day?

30. How certain are you of that?

31. What would be the height of the sixth plant after 2 weeks if it received 35 ml of water per day?

32. What prediction are you most certain about, or can you be just as certain about both? Explain.

**Data Sheet to Accompany Questions 26 and 29 to 32 in the Interview Guides**

Table 1: The Effect of Water on the Growth of Bean Plants

| Plant number | Amount of water per day (ml) | Height of plant after two weeks (cm) |
|---|---|---|
| 1 | 5 | 4 |
| 2 | 10 | 15 |
| 3 | 15 | 27 |
| 4 | 20 | 32 |
| 5 | 25 | 35 |

**Data Sheet to Accompany Question 26 in the Interview Guides**

Table 2: Results of an Investigation on Student Achievement and Study Time.

| Student Number | Overall term average (%) | Study time per week (hours) |
|---|---|---|
| 1 | 89 | 12 |
| 2 | 56 | 4 |
| 3 | 78 | 10 |
| 4 | 48 | 2 |
| 5 | 80 | 8 |
| 6 | 71 | 7 |
| 7 | 92 | 15 |
| 8 | 35 | 1 |

# Appendix B

## Transcripts and Corresponding Conceptual Inventories of Four Representative Interviews, One From Each Group

**Sample Transcript: Group A (Subject 1, School 1)**

I What was the title of your project?

S The title of my project was "What is Viscosity?".

I Where did you get the idea for the project?

S From a motor oil commercial.

I Would you like to tell me a little about your project? What is involved?

S Well, basically I used nine liquids and they were all different viscosities. I used four thin liquids and I tested them in a viscometer and I timed it. I used the thicker liquids in the Gibson and Jacobs filing and Sphere method. So that's how I timed the thick liquids and then what I did was to get the density of them and there was a really long formula. It was just a bit of substitution where I would just take all my times and data and compare two liquids to get the viscosity of the one that I didn't know using viscosity and times and everything important that I do. I tested at three temperatures: 22.5, 32.5, and 42.5 degrees Celsius. I made up a book and graphed all the viscosities of the liquids.

I How did you plan your experiment?

S What do you mean by plan?

I What kinds of things or sorts of things did you consider before you actually started doing your experiment?

S I had someone help me set it up from the university (that's where I got all my equipment from) and she just showed me how to operate the equipment and things. I just set it up in a way that it wouldn't have to be moved around too much, sort of like in a corner. I think that helped.

I Before you actually jumped into doing your experiment, were there certain things you had to think about?

S Yes, I had to think about how I'd graph the data I'd receive through my experiments and had to figure out how to put it all together so that it wouldn't be too complex for someone to understand. And that's about all I can think of.

I What is a hypothesis?

S My hypothesis (which was my educated guess) I guess you could say was that temperature change would have an effect on the viscosity of the liquid.

I What was it you said a hypothesis is? Give a definition of it.

S An educated guess of what I think is going to happen. What you are going to find out through the experiment.

I I have a list of six statements here and I want you to decide whether or not each is an example of a hypothesis. Give a reason for each decision.

S The first one is a hypothesis.

I Why?

S Because it seems to me that where it says "if" means it's a guess; you are not sure. I think it tells me that if that was a science project in a university in Canada, a research project would make a person more physically active and "then" take his pulse and see if there is an effect. That is what it seems like is happening to me.

I What about the next one?

S That doesn't seem like a hypothesis. Again it says "if", but this time it seems to be more in-depth (tiny invisible particles separating further and further apart). It just seems to me that it would be more of a conclusion.

I The next one now.

S That could be a hypothesis but again it could also be a conclusion. It seems more like a something that you would do to get a conclusion.

I So what is your decision?

S I'm not really sure. I think it could be either really.

I What do you mean?

S A hypothesis or a conclusion.

I And your reason?

S It seems that it's somewhere in between. Like it seems more like a hypothesis because there is no figures or anything involved.

I Pardon?

S Because there is no figures or definitions or anything. It's more of a hypothesis probably.

I But you are not sure are you?

S Not really no.

I Let's move on to number four then.

S That one wouldn't be a hypothesis because it seems more like something you would find in a book or something. It's just trying to tell you that when a plant's leaves turn yellow, it means it has probably died because it hasn't had enough sunlight.

Number five is definitely a hypothesis because they are saying that next year the acid rainfall will increase and be greater than ever before. So that's basically a guess; they are looking at their information and guessing at something else, so that would definitely be an educated guess.

I And number six?

S Well again number six seems more like a conclusion because a person doesn't use any words like "probably" or anything. It just seems to me that he tried it and he knows.

I So that one is what, a hypothesis?

S No it's not.

I Can you think of some variables or factors that were involved in your experiment?

S My main variable was change in temperature to the liquids. I'd say that was the main one I think. That's all I can think of because everything else was . . . it was really a controlled experiment.

I What do you think an independent variable is?

S An independent variable is like . . . I changes my temperature so it's something that would affect the outcome of the dependent variable. So I changed my temperature and that was the independent variable. The dependent variable would be the viscosity which was lowered as the temperature went up.

I How many independent variables did you have in your experiment, or is there a set number?

S I had about 15 or 16. I had a lot; I can't remember them all now. Five or six is all I can remember now.

I How many variables did you have that you changed?

S The only variable I changed was the temperature change. Everything else was controlled.

I So how many independent variables should there be in an experiment, or is there a set number?

S You don't really need a lot like I got. My experiment only needed one.

I How many do you think there should be in an experiment?

S There should be at least one. It could be a lot but usually in most experiments it's only one variable unless you're testing something.

I So why would there be just one variable?

S Well, because if you had two you would be doing two experiments really.

I Is an independent variable the same as a controlled variable?

S No it's not. It is the opposite.

I Explain.

S Well, the 15 or 16 controlled variables I had were all controlling everything you see. But then on the other hand the independent variable would be like your purpose for changing everything.

I What is a dependent variable?

S The dependent variable basically was the outcome and it's dependent because it depends on the changes that you make. The outcome would depend on the temperature change so the dependent variable would basically be the outcome.

I How many dependent variables were there in your experiment?

S Three I can think of right now.

I What are they?

S The 3 dependent variables would be (1) all the times; they changed your temperature, (2) viscosities themselves changed, and (3) density changed as well as the temperatures. They are all the dependent variables.

I How many dependent variables should there be in an experiment, or is there a set number?

S I don't really think there is a set number, it depends on the type of experiment you have . . . well, I changed the temperature as my independent and my dependent. I had three but really I only used one for my experiment purposes.

I What was the one you used?

S Viscosity. The other ones I just knew for myself. I didn't write them down.

I So what were they again?

S Density and time.

I Is a dependent variable the same as a controlled variable, or are they different?

S Not really because again a controlled variable is keeping everything the same. But your dependent variables can all be different because if you got a lot of independent variables you will have a lot of dependent variables as well.

I What is a controlled variable?

D That's a variable that is kept controlled during an experiment.

I What does it mean to control variables?

S It just means that for a variable such as a change in temperature, there is also control involved there. Where I used what's called a constant temperature bath, that could control temperatures for me. So I just set it at a certain temperature and it would control it at that temperature and it'll stay there. There are many others too, like my weight scale. I had to level it off using a little tiny bubble of air in a liquid that you could see through a glass (like this here and there on the tape recorder). I had to get the water inside the little tiny circle so that would tell me when it was leveled off. Some other ones would be such as cleaning up the glassware so that there is no interference so that when the liquid flows through, it wouldn't bring up on anything. I had a lot I can't remember right now.

I You just listed some variables you controlled. Can you think of any others you controlled?

S There were others I had written down but I can't remember them now.

I Why is it important to control variables in your experiment?

S Just so that it'll be valid and you wouldn't have all kinds of changes. So you would get the right answer. The outcomes would be affected if you didn't have controls. Then you could be completely wrong in your experiment.

I Can you give me an example from your experiment?

S Okay, say I didn't control temperature and I just ran water from the tap and stuck my hand in under and said "ah, okay that feels hot enough" and I brought it up and tested it. The next day I get tap water again and put my hand under until it feels the same as before. If it was warm in the room, it would seem to be colder to my hand. If it was really cold in the room, it would seem like scalding on your hand. But it could be the same temperature of water. So that would be one and that would greatly affect the outcome if you had different temperatures of water for supposedly the same temperatures. When you tested the liquids, it could be like 10 or 20 degrees.

I What is an inference statement?

S I don't know.

I What does it mean to infer?

S I'm not sure.

I Do you think there might be a difference between observing and inferring, or are they the same?

S I think inferring means that you just watch a couple of times and you guess what's going to happen afterwards.

I In your mind, what is an observation?

S It's seeing, feeling or hearing something. It is just basically using your senses to determine something about an object.

I I have a list of statements here and I want you to decide if each is an example of an observation. Give reasons for your decisions.

S The first one is an observation because you're using your senses. You are smelling a burning chemical.

In the second one you are using your senses. You are seeing that it's a yellow powdery substance.

Again, in the third one you are seeing. You saw the particles disappear, but then after that it says "because it separated into tiny particles too small to be seen." So that wouldn't be an observation because it was too small to be seen and you wouldn't really know that unless you used a microscope.

I So what is your decision on that one?

S If they used a microscope and actually saw the particles and they saw the particles dissolve and disappeared, then that would be an observation.

I As it's stated there, is that what you think it is, an observation?

S Well, here there is no mention of a microscope so I say it's not because they saw it in a container disappear. Just as it's written there I don't think it would be.

Number four is an observation because you are hearing a hissing noise.

The fifth one is also an observation because you are using another sense; you are feeling it.

In the last one you would see that the trees are smaller but then they go on to say "because of high winds and salty sea spray." They wouldn't be able to know that unless they went through a really long study. So in a way it could be an observation like in number three. But because there are other circumstances involved, I don't think it is an observation.

I What does it mean to interpret data?

S When you do your experiment, you have a whole pile of results and unless you can understand them and use them for your project, then they aren't very useful. So you have to know what you are looking for in your data and know what you are going to do with it and how to use it.

I Did you interpret the data or results in your experiment?

S Yes, well again I found that viscosity went down as temperature went up.

I I want you to look at Table 1 and make one general statement telling me what the data are saying.

S This data is telling me that the more water you add to a plant per day, the taller it is going to grow after two weeks.

I What about Table 2?

S The higher a student's average is, the more study he must have done.

I Is there a better way to say that?

S Yes. The more a student studies, the higher the marks.

I What is a prediction?

S A prediction can be similar to a hypothesis because it's a guess basically; an educated guess.

I What is the difference between a prediction and a hypothesis, or is there a difference?

S I don't think there is much of a difference, if any.

I So why are they the same?

S Well, in a hypothesis you are guessing (through something you read or something else) what will happen in your experiment. A prediction you can be guessing at something too. So I'd say they are the same.

I Looking at Table 1 again, let's assume there was a sixth plant and let's say that it was given 18 ml of water per day. I want you to tell me what you think the height would be after two weeks.

S It would be between 29 and 30 cm tall.

I How certain or sure can you be about that?

S Well, I found that between 15 ml and 20 ml of water there's a 5 cm difference in the height of the plants. So 18 is close to between 15 and 20. So 29 or 30 would be a close estimate to what the plant would be.

I What if the sixth plant was given 35 ml of water per day. What do you think the height would be after two weeks then?

S It's hard to predict really because the difference between plants one and two is 11 cm, between two and three is 12. Then it went down to five and then three, so it would be hard to predict really.

I What do you think though?

S It would probably be around 40, I guess.

I Which of these two predictions are you most certain about, or are you just as certain about both?

S I would be more certain about the 18 ml of water plant because here I have the actual data on both sides and I found that between them we have five. So I just got an average of that whereas here where they are changing, it's not just a regular pattern.

I Why is it important to control variables?

S So that everything would be maintained as the same. So you are not just saying that it is all the same but it actually is because you are controlling everything (trying to keep it all the same) so that your outcomes will be more valid than if you just didn't do any controls at all.

I So what do you mean by more valid?

S They would be closer to what you should actually have. Like in my experiment with all the controls, I checked some of the viscosities in a book I had and I found mine to be really close to these.

I What do you think the reason for that was?

S Well, I used a lot of controls so that would be the reason. But then again there is always a certain degree of human error. So another control would be that I did the experiment by myself so I could have a more accurate eye for measuring certain things. Like it is really precise. Someone else could look at a thermometer in a different way or something like that.

I So in this experiment here with the bean plants (Table 1), what would be some controlled variables?

S They controlled how much water they put in each day. They seemed to be very exact like 5 ml, 10 ml, and 15 ml each day. And over here they seem to be exact in their measurements: 4, 5, and 27.

I Any other variables that might be controlled here that might affect the experiment?

S Using bean plants. If they had used a couple of bean plants, a couple of marigold seeds and so on, then these plants can have different growth rates so it would be a different outcome.

**Sample Conceptual Inventory: Group A (Subject 1, School 1)**

**A) EXPERIMENTING**

*1.0 Planning an Experiment Involves:*

1.1 getting qualified people to help set up the project and to demonstrate how the equipment operates.

1.2 choosing the proper area to set up the experiment so it does not get disturbed.

1.3 thinking about how to represent the data collected and to put it all together so it is not too complex for others to understand.

**B) HYPOTHESIZING**

*2.0 A Hypothesis is:*

2.1 an educated guess about the outcome of an experiment.

*3.0 Identifying Hypotheses:*

3.1 A hypothesis involves an **"if... then..."** statement.

3.2 A hypothesis is not as detailed as a conclusion.

3.3 Hypotheses have no figures or definitions involved with them.

3.4 Hypotheses are statements about things that are not found in books.

3.5 Unlike conclusions, hypotheses have words of uncertainty like **"probably"** in them.

3.6 The only statements that can potentially be hypotheses are those that no one knows the answers to.

**C) IDENTIFYING AND CONTROLLING VARIABLES**

*4.0 Listing Variables:*

4.1 (Subject listed only one variable for his experiment because he said all the rest were controlled and therefore could not affect the results).

### *5.0 Independent Variable:*

5.1 An independent variable is something that the experimenter changes to affect the outcome of the dependent variable. It is the experimenter's purpose for changing things.

5.2 The independent variable is the reason why things are changed during experiments.

5.3 Although there is no set number of independent variables in an experiment, there is normally only one. An experiment with more than one independent variable is really more than one experiment. For example, if there are three independent variables, there are really three experiments being done.

5.4 An independent variable is the opposite of a controlled variable.

### *6.0 Dependent Variable:*

6.1 The dependent variable is the outcome of an experiment, which depends on changes you make with the independent variable.

6.2 There is no set number of dependent variables for an experiment. It depends on the experiment itself.

6.3 Dependent variables are not the same as controlled variables because controlled variables are those that are kept the same, but dependent variables can all be different; they can change.

6.4 If an experiment has a lot of independent variables, it will have a lot of dependent variables as well.

### *7.0 Controlling Variables:*

7.1 Controlling variables means making sure that everything is done as accurately as possible in an experiment.

*7.2 Controlling variables involves keeping everything the same in an experiment.

**7.3 Controlled variables are those the experimenter has control over. He or she decides how they will affect the experiment.

* Subject's superficial belief.
** Subject's deeper belief, revealed through probing questions.

7.4 Controlling variables involves being exact in measurement and ensuring that things used in the experiment are the same.

7.5 An experiment is well controlled if it has few variables.

*8.0 Importance of Controlling Variables:*

8.1 Variables in an experiment must be controlled to ensure valid results.

8.2 Experiments that have controlled variables will yield results closer to what they should actually be. That is, controlling variables helps ensure you get the right results.

8.3 Keeping everything the same is important so the experiment will be free from numerous changes.

**D) INFERRING VERSUS OBSERVING**

*9.0 Inferring:*

9.1 means watching something a couple of times and guessing what's going to happen afterwards.

*10.0 Observing:*

10.1 Any statement which shows use of the senses is an observation.

*11.0 Identifying Observations:*

11.1 Statements demonstrating the use of your senses to determine something about an object are observations.

11.2 Statements that give reasons or explanations for why something has been noticed are not observations.

**E) INTERPRETING DATA**

*12.0 Interpreting Data Involves:*

12.1 taking a pile of information and making it understandable, and therefore useable.

12.2 knowing what information to look for and pay attention to.

***13.0 Ability to Interpret Data:***

13.1 (Subject easily interpreted the data in Tables 1 and 2).

**F) PREDICTING**

**14.0 *A Prediction is:***

14.1 an educated guess about what the outcome of an experiment will be.

14.2 the same as a hypothesis because both are basically educated guesses.

***15.0 Interpolating Versus Extrapolating:***

15.1 Interpolating is safer than extrapolating because there is more information to guide you.

15.2 Extrapolating is more uncertain than interpolating because there is always danger involved in going beyond the available data.

**Sample Transcript: Group B (Subject 12, School 4)**

I What was the title of your project?

S "The Effect of Different Color Lights on Bean Seed Growth."

I Where did you get the idea?

S Well, our teacher handed out certain sheets which had various ideas and we were also interested in this project because it seemed original, which it kinda wasn't because we had another one next to us at the fair. But we basically got the idea from the sheet.

I Tell me about your project.

S Well, we took the different plants. We had seven plants in total and one had no light whatsoever, and the others had green, blue, red, yellow and white light. We had boxes made and separated so that no plant got light from the other plants. And we had them all hooked up with ceiling sockets and octagon boxes, and light bulbs were screwed into that and it was plugged in. We had the same wattage bulbs and the same amount of bean seeds, same amount of soil, same boxes, and same amount of water (except for the one in normal conditions, which was in my kitchen). We plugged in the lights for the same amount of time each day to see if it would affect it.

I How did you plan this project?

S What do you mean?

I What kinds of things did you consider before doing the experiment?

S Do you mean like how I had . . . where I got the board and everything or . . .?

I Sure.

S Well, we had it all written down weeks before we did it because we had to have lots of time to grow the plants and we got my mother to pick up seeds and we went to get the soil and the same size pots and everything. We wrote down all the controls so we'd know how to control them. We recorded all of our data to make sure that everything worked out even and fair. My father, with the help of Mike Abbott, did the boxes and we hooked them up in my living room and my rec room. It was the rec room first and then we had to move it up to the living room when we were going to the regional fair.

I Okay, what is a hypothesis?

S Our hypothesis was we thought that the yellow light would work best because it was like the sun and the white light would work the best because the white and yellow light are both the brightest.

I What is a hypothesis then? Give me a definition of it.

S Your best guess; like what you think would happen.

I In what?

S In terms of what would happen like in the end. Like "would your guess be the same as the conclusion of your results."

I Can you give me a statement of your hypothesis again?

S We thought that the yellow and white would work best because they are both the brightest and the yellow is like the sun.

I "Working best", meaning what?

S The plants would grow the best under that light.

I I have a list of six statements here and I want you to tell which are hypotheses and give the reason for your decisions.

S None of these really seem like hypotheses. They kinda seem like results.

I Okay, let's go with each one separately. So what do you think of the first one?

S That's not because they're making a statement that . . . as if though they have already done the project and it's finished . . . that a person's physical activity increases, his pulse rate will also increase.

I So you don't think that's a hypothesis?

S No, it doesn't seem like one to me.

I What about the second one?

S I feel the same for that one. I kinda feel the same for all of 'em.

I Why don't you think the second one is a hypothesis?

S Because they're saying that the particles will separate and move further apart if an ice cube melts.

I How about the third one?

S I think that's results too kind of, because the solid will dissolve and will also increase if the temperature of the liquid increases.

The fourth one, they're saying that the plant . . . that's definitely a result because it has died already. They're not saying that "it will" probably die because of lack of sunlight. They're saying "it has" probably died and that seems like past tense. So it seems like the project is already finished.

I What about number five?

S That seems like a hypothesis because they're giving you a guess for the next year as though they have already done it. They seem about the. . . . They have looked up the results for the past five years but they're looking . . . they're taking a guess about next year.

I Number six there now.

S They're. . . . It seems like results to a certain degree because they're saying that there will also be an increase in the growth rate because of the amount of light a cucumber plant receives. But to a certain degree I feel these are all hypotheses 'cause they're saying "if", which is in every hypothesis. Like "if" a person's activity increases.

I How would you reword that first statement to be a hypothesis?

S For a hypothesis?

I Yeah.

S Well, we had a problem at the science fair and down in the gym because they said you can't say "we think" or "we believe." We didn't know what to put in there. But we left our "we think" there. But if I was doing it with a partner and everything I would say "We believe that if a person's physical activity increases, his pulse rate will also increase." You just have the "if" there. So it really can be a hypothesis if you look at it in that term.

I What about the second one then? Would you be able to reword that?

S To a certain degree you could. To a certain degree you could reword them all by saying "we think and we believe. . . ."

I But as they stand there, you think most of these aren't hypotheses? You said number five is a hypothesis, but the others you don't think so?

S Well, I think number four definitely seems like results because they're saying it had died already. It's in past tense. But the rest can be just changed a little (if none at all) to make it a hypothesis.

I What were some variables or factors you felt could affect the outcome of your experiment?

S Some things that might have went wrong to change the results?

I Sure. Some factors or conditions you had to consider.

S Well, there was all the moving around. We had to move around a lot. We had to take it to the school. We had to leave it in fact, in the lab overnight one night, which wasn't very good because it got no light. But sometimes the plants didn't get much light because we had to unplug them all and go and get new ones. So some had new ones and some had old ones which kinda mighta affected it, but probably not too much. We also had to bring it from my rec room downstairs which was sometimes heated by the wood stove and sometimes by electric heat and sometimes it wasn't heated at all. And when we were watering 'em we had to . . . we forgot once about unplugging them both and taking the thing off and we just took . . . did one at a time which might have affected it a bit because some might have had just a little more light than another. And that's basically it.

I Okay, what is an independent variable?

S Something that you cannot affect. Something that will happen but you can't do anything about it.

I What was an independent variable in your experiment then?

S Well, the heat certainly wasn't, 'cause we couldn't really do anything about that.

I It was or it wasn't?

S It wasn't like. . . . I mean we could have done something about it. Like we could have had all the heat off or all of it on the same temperature but we didn't. And the transporting around, we had to do that. We couldn't exactly bring everyone over to my house and we couldn't have it left at the school. So we couldn't do anything about that and that's basically all I can think of.

I What factor or condition did you change as you did your experiment?

S What do you mean?

I Like was there something you changed throughout the experiment, or was there something in that experiment that was changed?

S The light bulbs. That was about it.

I Explain that. How were they changed?

S Some had new ones and some were getting new. . . . Well, we started off with all new ones but some ran out at different periods of time. So we had to unplug them all and then go out and buy new ones.

I How many independent or manipulating variables did you have in your experiment?

S I can only think of the heat really, the one we couldn't do anything about. And the temperature of the water. We couldn't do anything about that, but I don't think that would affect it too much.

I How many independent or manipulating variables should there be in an experiment, or is there a set number?

S I don't think there is a set number, like the less . . . least possible amount I would imagine.

I Is an independent variable the same as a controlled variable?

S No.

I How are they different?

S Well, controlled is something that you are doing that you are making sure that it will be the same. Like everything will be the same, or everything is different. But in our case everything was the same. But an independent variable can sometimes change your thing. . . . Some things can be different and some things can be the same.

I What is a dependent variable?

S One that you can change. Like one that you did something about that you couldn't . . . you could make different but. . . .

I Okay, what is a responding variable (which is the same as a dependent variable)?

S I wouldn't know.

I So you said the dependent variable you could do something about?

S Yeah. Like it was something that happened but it happened from your own doing.

I So what was the dependent or responding variable in your experiment?

S The heat. We could have done something about the heat but it wasn't a different heat for each plant (except for the one in the kitchen which was under natural conditions). But we could have done something about the heat. We could have had it all off or all on.

I How many dependent or responding variables did you have in your experiment?

S A lot. We had 10 or 12.

I Can you just list a couple here now?

S Dependent variable means things that you had control of, right? So we had the same size pots, same amount of soil, same amount of seeds, same amount of water, same amount of light, same wattage of bulbs, and same amount of space.

I So how many dependent or responding variables should there be in an experiment, or is there a set number?

S I don't think there is a set number but the major factor is to have them controlled.

I Is a dependent variable the same as a controlled variable?

S Yeah.

I So how are they the same?

S Because dependent variable you are controlling it and controlled variable you are controlling it too.

I In your experiment then the different colors of light bulbs; what kind of variable is that do you think? Did you control that?

S What do you mean by controlling it?

I Is that a controlled variable?

S Yes. Well, we took them all and made sure each plant had the same color. Like it said this plant had a yellow stick so this plant had to go under yellow. A plant with a green stick had to go under the green. It never went under a different light, if that's what you mean.

I So you did control the light?

S Oh yes. We plugged it in for a certain number of hours each day.

I What is a controlled variable?

S It's one you controls in an experiment.

I What does it mean to control variables?

S To have them all the same. To make sure that all your plants are receiving the same amount of water and same amount of light, the same space, the same amount of air and so on.

I Are those some that you controlled in your experiment?

S Those were some.

I Are there some others?

S All the plants had the same temperature. They may have had different temperatures on different days, but they were the same temperature all together in general, except for the one we had in normal conditions. And we controlled their light, their water, their space. . . .

I Why is it important to control variables?

S Because it affects the experiment amazingly. Like if you had a different amount of water for one and a different amount of water for another one, one is probably gonna grow more and the other probably might drown. Anything could really happen to affect it.

I You made sure to give it the same amounts of water and everything?

S Oh definitely. With a tablespoon. We made sure we took the water in a tablespoon and we measured it off for each plant. Even if the plant . . . some plants were really dry and really wet, we still had to give it the same amount. Like the one under no light was sometimes a bit wet, but we still had to give it the same amount of water as the rest or the others would have withered.

I What is an inference statement?

S I don't know.

I What does it mean to infer something; to make an inference?

S I don't know.

I Is there a difference between inferring and observing, or are they basically the same?

S I wouldn't be able to tell you. That's where I'm lost.

I What is an observation in your mind?

S An observation in my mind is something that you see and you can say that you've seen this and that it is sticky because I've felt it.

I So you can see stickiness then?

S Oh no, but you can feel it but an observation is really is seeing. So . . . but they still could have felt it, which is. . . . They observed and they felt it and they observed when they felt it and it was sticky.

I So an observation is seeing things?

S Yeah.

I So in number one in this list then, "the burning chemical had a strong choking smell." What would you see there?

S You wouldn't see anything unless it was cloudy or something. But your nose felt it . . . nose smelled it. So "you see" that this is smelly.

I So would that be an observation?

S Yeah, I think so.

I Look at this list and decide if each is an observation or not and give reasons for your answer.

S Number one is an observation because they're saying that this chemical that was burning had a strong choking smell. So they had seen the . . . smelled the chemical that was burning and they had decided it was a strong choking smell.

I How about number two?

S Yeah, that's an observation too because they are saying that the chemical that was used in the lab they saw it. They witnessed it and said that it was yellow and powdery.

I And number three?

S Yeah, they saw this too 'cause they have actually witnessed it disappearing so they could. . . . Yeah, it's an observation because they say that the particles are too small to be seen, and it disappeared because it separated into these tiny particles.

The fourth one is an observation because they heard the hissing noise. They say that when the substances were added together there was a hissing noise and they heard it hiss.

I What about number five?

S They felt one of the objects which made it sticky. So number five I think is an observation too.

I And the reason for that again?

S Because they felt the objects so they could feel that they were sticky.

Number six. They saw the trees in the beach and . . . I don't think this is an observation. Like it could be an observation because they noticed that they were smaller because of the high winds and salty sea spray. But how did they know it was the winds and salty sea spray which made the trees on the beach smaller? So they don't really know that the trees on the beach were smaller because of the wind and the salty sea spray.

I So what do you think?

S It couldn't be an observation. That might be what they felt. Like they thought that it might have been because of that, but they can't prove it unless they have . . . (indefinite pause).

I What does it mean to interpret data in an experiment?

S To like. . . . Kind of say, well this is what you think the results are gonna be. I don't really know.

I Did you people interpret the data or results in your experiment?

S Yeah, I think we. . . . When I think of interpreting results, I think it is kind of a hypothesis; like you are thinking this is what's going to happen and the results are going to say this, and this is what you think that your results are going to say.

I Here is Table 1. What is it saying? Give one summary statement.

S I think that this table here is saying that the plants . . . the more water you give them except for number one (the first two weeks), that these plants grew highest when they were fed a little. Like I mean you feed this plant 10 ml of water, it's gonna grow 15 cm which is growing pretty good. I mean our plants didn't really grow that high. Ours just reached 15 cm, but these reached 35 cm.

I So what are the data telling you?

S Water does affect the height of the plants.

I Anything else you want to say about it?

S No.

I How does the water affect the height of the plants?

S Well, it kept them growing but if these plants didn't. . . . If they had compared a different plant that had no water at all over how many weeks this was (10 weeks, or whatever), then they could say . . . they could compare. Say this plant that had no water didn't grow much at all as compared to this plant that had water. It grew 35 cm.

I What about Table 2?

S The longer you study and study hard, then it's going to affect your mark. It's going to affect your grade.

I How?

S Well, this poor person here (well, I can't call him poor), this person here who only studied a hour only got 35% and the person with two hours had 48%. But the person who studied 15 hours got 92%, and 12 hours got 89%. So the more you study, I think the higher you're going to get.

I Now then, what is a prediction?

S What you predict is going to happen. What you think is going to happen. It's sort of like a hypothesis.

I So is there a difference between a prediction and a hypothesis, or are they basically the same?

S Basically the same.

I Would you explain that?

S It's . . . 'cause a hypothesis is a guess of what you think is going to happen in your results. And a prediction is something you think is going to happen in . . . something that you are saying that you think is going to happen in your results. Like if your results say that this certain light worked the best and you predicted that this light will work best and your hypothesis was "this light will work best," then you are saying this light is going to work the best and your results are also proving it. So a hypothesis and a prediction are the same; giving your guess of what you think is going to happen in the end after your experiment.

I Look back at Table 1 again now. Let's assume a sixth plant and it was given 18 ml of water a day. What would be its height after two weeks?

S Somewhere between 15 and 22 cm?

I Can you pin it down?

S Oh, I was looking at the wrong one. Somewhere between 27 and 32 cm.

I So can you pin it down?

S It could be around 30 or 31 cm.

I So how sure are you of that?

S It seems pretty sure 'cause 15 ml gave you 27 cm and 20 ml gave you 32 cm. So it has to be somewhere between these and an estimated guess would be 30 or 31 cm.

I What if the plant was given 35 ml of water each day? What would be the height of the plant then?

S Around 39 cm.

I Which prediction are you most certain about, the first one or the one you just made, or are you just as certain about both?

S Basically just as certain about both. Although the second one it seems you can do more with it kind of to a certain degree 'cause you're saying that it grew 32 and 35. So it's three like. And 25, so you just double 25 to 35. So you just double three and three which is six. So you just add on six or so. But you can't really do that 'cause it grew less and less each time. So you're basically just as certain about both.

I Earlier we were talking about controlling variables. Why is it important to control variables?

S Because if you didn't control them it would affect your experiment.

I How?

S Well, if you gave this plant only 5 hours of light and this one 10 or 12 hours of light, I mean naturally one is going to grow more than the other. It's going to affect it; it's going to change the results. You have to control it to make sure it's the same. Like you can't hand in the results and say you gave them different amounts of light, 'cause they're not gonna take that. They look for controls.

I Look at Table 1 again and see the experiment. What type of variable would the amount of water you give the plants be? Would it be an independent, dependent or controlled variable?

S They didn't control it. Well, they gave it 5 more each time. Well, then they say they gave number one 5 ml and number two 10 ml, so it wasn't controlled.

I So what kind of variable was that then?

S A dependent variable.

I Why?

S Because they're the ones who changed it around to make it different.

I What about this one here (height of the plants)? What variable would this be?

S That wouldn't be a variable. That would more or less be the results of what happened.

I What factor or variable is this though? Is it a controlled variable?

S No.

I Is it a dependent variable?

S Yes.

I Why?

S Because. No it's independent sorry, because they didn't affect how much it grow. Well they could have, but they didn't control the amount of water over here. So they can't control how much it's growing.

I So that makes it independent, does it?

S I think so.

I That's it. Thank you.

**Sample Conceptual Inventory: Group B (Subject 12, School 4)**

**A) EXPERIMENTING**

*1.0 Planning an Experiment Involves:*

1.1 preparing for the experiment weeks prior to doing it.

1.2 selecting the appropriate materials and getting them together before the experiment is to be started.

1.3 taking time to ensure variables are controlled.

1.4 knowing how the data will be collected and recorded.

**B) HYPOTHESIZING**

*2.0 A Hypothesis is:*

2.1 the experimenter's best guess at what the outcome of an experiment will be.

*3.0 Identifying Hypotheses:*

3.1 Those statements that are already known to be true are not hypotheses.

3.2 All statements with words like "**it will**" are hypotheses but those with words like "**it has**" are not hypotheses.

3.3 Those statements with the word "**IF**" at the beginning are hypotheses.

3.4 Statements that start with "**We think**" or "**We believe**" are hypotheses because they state what someone thinks.

3.5 Hypotheses statements are not the same as results.

**C) IDENTIFYING AND CONTROLLING VARIABLES**

*4.0 Listing Variables:*

4.1 (Here the subject just discussed some of the problems experienced while doing the experiment which could have affected the results).

*5.0 Independent Variable:*

5.1 An independent variable is one that the experimenter cannot change, or has no control over. It's something that happens regardless of what the experimenter's intentions are.

5.2 Although there is no set number of independent variables for an experiment, the fewer there are the better. Ideally there should be no independent variables in an experiment.

5.3 An independent variable is not the same as a controlled variable because it cannot be manipulated by the experimenter, but controlled variables can be manipulated by the experimenter.

*6.0 Dependent Variable:*

6.1 A dependent variable is one the experimenter can change. Any changes noticed in the variable, are because of the experimenter's manipulation.

6.2 Dependent variables are those the experimenter has control of. He or she decides what variables to keep the same in the experiment.

6.3 There is no set number of dependent variables in an experiment. The major concern is to ensure they are all controlled.

6.4 A dependent variable is the same as a controlled variable because the experimenter controls both.

*7.0 Controlling Variables:*

*7.1 Controlled variables are those that the experimenter controls. He or she decides when, and by how much, certain variables will affect the experiment.

**7.2 Controlling variables means keeping all of them the same during the experiment.

* Subject's deep belief pattern.
** Subject's superficial belief pattern.

*8.0 Importance of Controlling Variables:*

8.1 If variables aren't controlled, the results of the experiment will be changed, and will therefore not be accurate or valid.

**D) INFERRING VERSUS OBSERVING**

***9.0 Inferring:***

9.1 (Subject did not know what inferring was and could not answer if there was a difference between inferring and observing).

***10.0 Observing:***

10.1 Observing is seeing.

***11.0 Identifying Observations:***

11.1 Observing is taking note of things mainly by use of your sense of sight, but also by use of the sense of touch, smell and hearing.

11.2 Statements that provide reasons for what has been noticed are not observation statements.

11.3 Observing is really seeing.

**E) INTERPRETING DATA**

***12.0 Interpreting Data Involves:***

12.1 thinking how the data of an experiment will turn out. Interpreting data is like a hypothesis.

***13.0 Ability to Interpret Data:***

13.1 (Subject had difficulty interpreting data from Table 1, but did manage to interpret data from Table 2 fairly well).

**F) PREDICTING**

***14.0 A Prediction is:***

14.1 what you think the outcome of an experiment will be.

14.2 the same as a hypothesis because both are guesses of what the outcome of an experiment will be.

## *15.0 Interpolating Versus Extrapolating:*

15.1 Both interpolating and extrapolating have a degree of uncertainty and one can be just as certain about both types of predicting.

**Sample Transcript: Group C (Subject 24, School 8)**

I What was the title of your project?

S "Maintaining Life in Space."

I Where did you get the idea for the project?

S Well, like I was going to Florida and we were going to the Kennedy Space Center. So I wanted to do something on space and that's not exactly what we had planned to do, but the science teacher told us to do that. Like it was something that you could get results fast, in a short period of time.

I Tell me about your project.

S Well, we took a movea plant and ah put a pipet over 'em and turned different kinds of light on them. And we put all of it down a test tube. And so the plant would give off oxygen and the water would come out of the pipet. So we could record how much oxygen is given off and how much it photosynthesizes during the day. And different kinds of light made it photosynthesize more, like blue light made it photosynthesize the most and I think orange made it photosynthesize the less.

I How did you plan your experiment before doing it?

S Well, we planned to do it a different way than we actually did it. We planned to put a clamp over the top of a test tube and record it a different way, but it didn't work. So we had to use a pipet 'cause it was smaller and you could get the results quicker. Like we didn't have to leave the light on as much 'cause we could see it better.

I What other types of things did you consider before doing your experiment?

S What kind of light you'd use and what color and what kind of plant. We had to go and buy the plant and everything we'd need. We had to write a list up so the teacher could get it for you. And that's about it.

I Okay, what is a hypothesis?

S That's like your own guess as to what the results is gonna be.

I What hypothesis did you have in your experiment?

S Well, we thought that the green light would give off . . . would produce the most oxygen on the plant, but it didn't.

I Can you remember how you had the hypothesis worded?

S Ah I think we said "The green light will make the plant photosynthesize most."

I I have a list of statements here and I want you to read each one and decide if it is an example of a hypothesis, and give a reason for your decision.

S Well, I think it's (number one) a hypothesis because like the person may not know that already and so they might have to test that to see if it actually happens.

I don't think number two is because it's like that's a . . . a theory, like the Kinetic Molecular Tneory. Like that's proven already. I suppose the first one is too but I don't know.

Well, I think the third one. . . . Well, it is kind of like you already know that really. But it's like you could still do an experiment on it to make sure it's true in your own head. Like. . . .

That's not a. . . . Number four isn't because ahm it's like you're saying it has "probably" died because of lack of sunlight. It. . . . I don't know. It just doesn't seem to me like it is.

I Why would you say that? Is there something about it that might cause you to say that?

S You can't prove how the plant died no matter what you do, so it doesn't really matter.

Number five is 'cause it's guessing what will happen next year because of what has happened before. They think what will happen.

Number six is 'cause you're guessing that it will increase, like you can't tell for sure until after it grows.

I Would you like to tell me the basics of your experiment again? You had a plant . . .

S We had four or five different pieces of a plant. It's called a movea. And we put it in a test tube and put a pipet over the top of the plant.

I And gave it different amounts of light?

S Yeah, different colors of light, and we recorded how much oxygen was in the pipets at the other end of it.

I Could this statement be a hypothesis of your experiment: "Plants receiving yellow light will grow faster or perform more photosynthesis than plants in other types of light"?

S Yes.

I What about "The reason photosynthesis was greater in one plant was because of the type of light that it received"?

S Not really 'cause we didn't know if one was going to photosynthesize most before. We didn't know, they might have been the same.

I What were some variables or factors in your experiment?

S Like what ones? Independent or what?

I First of all I'm just asking you to give me a general statement on the different types of variables, or some variables that you felt could have affected your experiment.

S Color of light, the time you left the light on, the size of the pipet, the type of plant you used, how big the plant was, how far away the light was from the plant, that's about it.

I What is an independent variable?

S That's the variable that you change to get your results of your experiment. Like we changed the color of our light, the color of the light used.

I How many independent variables did you have in your experiment?

S One.

I How many should there be in an experiment, or is there a set number?

S Well probably I guess one 'cause you're trying to find out one thing at a time, right?

I Is an independent variable the same as a controlled variable?

S No, an independent is ah . . . is something you should change, and a controlled, you shouldn't change.

I What is a dependent variable?

S That's like the results that you would get. Like which light made the plant photosynthesize the most. That was the dependent variable.

I Are you pretty sure about that?

S Not really, but I'm pretty sure.

I How many dependent variables might there be in an experiment, or is there a set number?

S Only one.

I Is that what you had in your experiment?

S Yes.

I Is a dependent variable the same as a controlled variable?

S No, a dependent variable is your result and controlled variable is something you shouldn't change.

I What does it mean to control variables?

S I don't know.

I When students talk about how they control variables in their experiments, what do they mean?

S I don't really know, like I know what a controlled variable is, but I don't think that's what you mean.

I Okay, what were some variables you controlled in your experiment?

S I don't think we did.

I You said you know what a controlled variable is. So what is it?

S That's like you're not allowed to change it 'cause it will alter the results of your experiment. You gotta keep the same type of plant every time and the same size plant every time.

I What were some variables you controlled in your experiment then?

S Well, the size of the plant and the pipet. We used the same pipet and used the same amount of water in the pipet and test tube. We kept the light the same distance from the plants. The only thing we did was change the color of the bulbs. Actually, it wasn't the color of the bulb but a color put in front of the bulb.

I Can you think of any other controlled variables in the experiment?

S How long we kept . . . left the light on.

I In your experiment did you leave the light on for different amounts of time?

S No, we left them all on for the same time 'cause we used the same type and size of plant.

I Why is it important to control variables?

S 'Cause your results won't be accurate if you don't control your variables.

I What do you mean by accurate?

S Like, they won't be scientifically correct because things were changed and everything. It's like if you . . . I don't know, but it's like if you're runnin' around the track or something. It's not fair to take your results from the third time he went around and if you take someone else's from the first time he went around 'cause he'll be tired, right?

I What is an inference statement?

S I don't know.

I Do you think there is a difference between inferring and observing, or are they the same?

S Well, I guess they're a little bit different.

I How?

S I don't know because I don't really understand what an inference is.

I What is an observation in your mind?

S Something you notice without going out of your way to find it.

I I have another list of statements here and I want you to decide which are observations and give reasons why.

S The first one's an observation because it's just . . . you didn't actually burn the chemical to see if it had a strong choking smell. You didn't burn it just to see that. You must have burned it for a reason. You didn't burn it just to see if it had a bad smell.

I So what is your reason again for saying that is an observation?

S 'Cause like you didn't burn it to see if it had a smell. You just noticed that.

I Okay, how about the second one?

S It's an observation 'cause you just noticed it. You didn't take it out and see if that was yellow and powdery.

The third one is not an observation because it's like they must have examined it 'cause you wouldn't know they separated into tiny particles too small to be seen unless you actually looked at it under a microscope or something.

The fourth one is an observation 'cause you just noticed there was a hissing noise.

The fifth one is an observation because you just noticed that it felt sticky. You didn't go out and say "well, I'm going to try to find something sticky now."

I So if you went out and said "well, I'm going to try to find something sticky now," what would that be?

S I have no idea but . . .

I You don't think that would be an observation?

S No, not really.

Number six isn't an observation because like you . . . you didn't just notice they were small. You noticed . . . you had to go and find out why and everything. It's like you just know.

I What does it mean to interpret data?

S Well, to find out what it actually means and what actually you can do with that information. Like we did our experiment about interpreting, or like we interpreted that if you took plants into space, you could stay there longer if the space ship's light was blue light because the plants produce more oxygen, and you'd have oxygen for longer then.

I Why do plants produce more oxygen with blue light?

S Well, we read a lot of books and stuff about it before, and it said that it was something about filtering out the other color lights and they respond most to blue light.

I Respond most to blue light, meaning what?

S They photosynthesize the most.

I Here is Table 1 showing results of a science fair project. Give one summary or concluding statement about the results.

S The more water given to a plant, the more it will grow.

I What about Table 2?

S The more studying that you do, the more it will bring up your marks; the better you will do in school.

I Did you interpret the data or results in your experiment?

S Yeah.

I What interpretations did you make?

S We said that like if you brought blue light into space, it will allow you to stay there longer. The plants would photosynthesize more and you'd have more oxygen for longer periods of time.

I What is a prediction?

S What you think will happen I guess.

I So is a prediction the same as a hypothesis, or are they different?

S Sort of. Well, a prediction I guess you just . . . is what you think will happen. But a hypothesis is supposed to be an educated guess after you read about it and find out about your topic.

I Here is Table 1 again and I want you to assume there was a sixth plant and it was given 18 ml of water per day. What would be its height after two weeks?

S Probably around 30 cm.

I How sure are you about that?

S I guess you can be sort of sure but you can't be exactly sure 'cause you haven't done the experiment. So you don't really know.

I Based on this table, how sure can you be?

S Well, there was a difference of 5 ml here and over here a difference of 5 cm. So if you say that each milliliter will give it 1 cm . . . you can say that but it's like between these two was 9 cm. So you can't actually say that it will be 1 cm for every ml, but that's what you think . . . assume 'cause it's all the data you're given.

I What if the sixth plant was given 35 ml of water per day? What would be the height after two weeks then?

S Probably around 40 cm.

I Which of these two predictions are you most certain of, or are you just as certain about both of them?

S I'm more certain about the first one because it's like you have the one before and the one after. So it's like you can kind of guess in between. But this one right here (the last one) is like it seems like it's kinda slowing down between this and this, and this and this (referring to the data in the table). So you don't really know. It might only be 1 cm, 'cause it's like there's only 3 cm and then there's 5 ml. So it could be six but it could be only one or two.

I What did you say an independent variable was?

S A variable that you can change, like we changed our color of light.

I What are controlled variables?

S Variables that you shouldn't change because it will alter the results in your experiment and you won't be accurate.

I Glance back at this list again and decide if they are observations or not.

S The first one I think is an observation because it's like you just observed that. You didn't go out . . . set out to find if that chemical has a strong smell.

The second one I think is an observation because you just noticed that it was yellow.

The third one I think isn't an observation because you obviously had to look it up . . . look under a microscope to see it. So you had to go find out what actually happened.

The fourth one I think is an observation because you just noticed that it had a hissing noise.

The fifth one I think is an observation because you just noticed that it was sticky.

The sixth one I think isn't an observation because you went and found out why the trees were smaller.

I Okay, do you have any questions?

S No.

I Well, thank you for your help.

**Sample Conceptual Inventory: Group C (Subject 24, School 8)**

**A) EXPERIMENTING**

*1.0 Planning an Experiment Involves:*

1.1 deciding on the best way to do the experiment by doing trial runs and leaving room for modification if necessary.

1.2 selecting the appropriate materials for the experiment and ensuring they are available when needed.

**B) HYPOTHESIZING**

*2.0 A Hypothesis is:*

2.1 the experimenter's own educated guess of the outcome of the experiment.

*3.0 Identifying Hypotheses:*

3.1 Statements about things that are not known already are hypotheses, providing they can be tested by experimentation.

3.2 Statement that are already known to be true are not hypotheses.

3.3 Hypotheses are not the same as theories.

3.4 Statements with uncertain words like **"probably"** are not hypotheses.

**C) IDENTIFYING AND CONTROLLING VARIABLES**

*4.0 Listing Variables:*

4.1 (Student easily listed several important variables for her experiment).

*5.0 Independent Variable:*

5.1 An independent variable is the variable that the experimenter changes to get a set of results.

5.2 There should only be one independent variable in any experiment so that its effect can be more clearly observed.

5.3 An independent variable is different than a controlled variable because it is changed in an experiment, but a controlled variable is not.

*6.0 Dependent Variable:*

6.1 The dependent variable is the result of the experiment.

6.2 There is only one dependent variable in an experiment.

6.3 A dependent variable is different than a controlled variable because it is the observed results of an experiment, while a controlled variable is one that must remain constant.

*7.0 Controlling Variables:*

7.1 Controlled variables are those that must not be changed during an experiment because they will alter the results, thus making them less accurate.

7.2 In an experiment, all variables are kept the same except for the one you are testing.

*8.0 Importance of Controlling Variables:*

8.1 If variables aren't controlled, the outcome of an experiment will not be accurate or scientifically correct.

**D) INFERRING VERSUS OBSERVING**

*9.0 Inferring:*

9.1 (Student did not know what an inference was).

*10.0 Observing:*

10.1 Observing is noticing things without deliberately trying to find it out.

*11.0 Identifying Observations:*

11.1 Statements that describe things that were accidently noticed are observations.

11.2 Statements that describe things that have been carefully examined are not observations.

**E) INTERPRETING DATA**

*12.0 Interpreting Data Involves:*

12.1 attempting to find out what they actually mean.

*13.0 Ability to Interpret Data:*

13.1 (Student interpreted information in Tables 1 and 2 with ease).

**F) PREDICTING**

*14.0 A Prediction is:*

14.1 what you think will happen.

14.2 different from a hypothesis because a hypothesis is a more educated guess that results after a topic has been researched.

*15.0 Interpolating Versus Extrapolating:*

15.1 Interpolating is safer than extrapolating because there is more information there to guide you.

15.2 Extrapolating is more uncertain than interpolating because it goes beyond the data given.

**Sample Transcript: Group D (Subject 32, School 16)**

I Have you ever been involved in a science fair?

S No.

I Have you ever carried out an experiment in science?

S Yes.

I Okay, what were they?

S Ahm, well basically it's just like class experiments and things with like supervision of the teacher in chemistry basically. Nothing in biology I don't think.

I The rest of the questions I will ask you deal with the following experiment. I want you to suppose or assume that you were going to carry out an experiment to see "how different amounts of light affect the growth of bean plants," okay? This sheet is here so that if you forget the experiment you can glance down to remind you.

So let's assume then you were going to carry out this experiment. How would you plan the experiment?

S Ah okay, I'd have the bean plants in front of the southern facing windows (so they'd get lots of sun), a regulated water, a control. I suppose I'd have different amounts of water, different amounts of light, hm the soils. I guess I'd have different types of soil.

I So what other things would you consider before you jumped into doing the experiment?

S The different types of bean plants, like a healthy type, you know. I can't really think of anything else.

I Okay. So then, if you were going to do this for a science fair, would there be anything else that would come to mind before you jumped into the experiment? Like would you set down and say "now let's see, how am I going to do this?" If you would, what other things would come to mind?

S Well, I mean. . . . Like I said, I'd have a control like regular sunlight and water and you know . . . and I don't know, like basically just different . . . like this amount of sunlight and no sunlight and very little water and things like that.

I What is a hypothesis?

S Ah it's a statement or idea about the project before you actually find out the conclusion of the thing.

I Okay, can you get a little more specific?

S Ahm. . . . On this particular one?

I Yes, okay what would be a hypothesis for this one?

S Ahm. . . . Okay, that ah . . . the amount of sunlight and the water on bean plants directly influence the growth of the bean plants.

I Here is a list of statements. I want you to decide which ones are hypotheses and give your reason for your decisions.

S Okay. (Reads number one silently). Well, I think that's more of a conclusion, the first . . . okay, the second . . . (indefinite pause).

I Just let me ask you, how would you reword the first one to be a hypothesis then? Or can it be reworded to be a hypothesis?

S If a person's physical activity increases, then his pulse rate "should" then also increase.

I Okay.

S I don't think that is either really.

I The second one?

S Yeah. If an ice cube melts. . . . Well, I don't really know.

I Okay, if you wanta come back to it, that will be fine.

S Okay (reads number three silently). I think that's more of a conclusion than a hypothesis.

That's a . . . the fourth one I think is a hypothesis.

I And the reason for that?

S Because it's not definite. "It's 'probably' died because of a lack of sunlight."

I think the fifth one is a hypothesis too because "it is 'likely' that next year's acid rainfall will be greater than ever before." It's not definite.

The sixth one I think is a conclusion.

I Okay, back to number two now then.

S Conclusion.

I How would you reword say number two or number six to make it a hypothesis?

S If an ice cube melts, it is likely that tiny invisible particles separate and move further apart.

I Okay, what about number six then?

S If there is an increase in the amount of light a cucumber plant receives, there will probably be an increase in the growth rate.

I Now, do you think you can give me another hypothesis you could investigate for this experiment?

S Ah the greater the amount of sunlight, probably the greater amount of photosynthesis within the bean plants.

I Okay, would this be an example of a hypothesis? "As the amount of sunlight increases, the growth rate in the bean plant will also increase."

S I think the word "should" . . . (indefinite pause).

I The word "should" should be put there?

S Mm mm.

I What are some variables or factors that could affect the results of this experiment?

S You mean could limit it or . . .?

I Anything that you'd have to consider? Certain things that you'd have to consider, because they could potentially affect the results?

S Okay, sunlight, the amount of water, the proper planting, the proper size pot, ahm . . . the temperature I guess. I can't think of anything else.

I Okay now, what is an independent variable?

S Ahm . . . independent variable is one that is not influenced by the experiment such as the amount of sunlight. It's sort of like the dependent variable but it's opposite of it. The dependent variable would be like the growth of the bean plants.

I How many independent variables would there be in this experiment?

S I think three; temperature, water, and sunlight.

I How many should there be or is there a set number?

S I don't think there is a set number, but the less possible.

I Okay, is an independent variable the same as a controlled variable, or are they different?

S I think they're pretty well the same.

I Would you like to explain that?

S Okay, well an independent variable is like, is not . . . you know . . . is not dependent on the experiment. And a controlled variable, well that's pretty well what you control and you control an independent variable too. You . . . so it's not dependent on the experiment either.

I So is there anything else about them that's the same?

S (Long pause).

I So what would be your definition of a dependent variable then?

S One that . . . the variable that is dependent on the independent variable. I don't know how to state it.

I You said the dependent variable is a variable that depends on the independent variable, and in this experiment you said the dependent variable was what?

S The bean plants. The growth rate of the bean plants.

I How many dependent variables would there be in this experiment?

S One. The growth of the bean plant.

I Okay, how many should there be, or is there a set number?

S There should be only one.

I Is a dependent variable the same as a controlled variable, or are they different?

S No. Okay, well a dependent variable, that's what happens under the controlled variable. That's what you do, like how you control it . . . how you . . . I can't state it. Ahm, well one like the dependent variable depends on the controlled variable and the independent variable. I don't know.

I Okay, so in this experiment here (shows subject Table 1), what would be the dependent variable?

S The growth of the bean plants.

I And what would be a controlled variable?

S The amount of sunlight or the amount of water.

I What is a controlled variable?

S It's a variable. . . . I'm not sure.

I In carrying out this experiment you'd have to be concerned about controlling variables. What does it mean to control variables?

S Well, I s'pose you'd want to be able to compare and contrast the growth of the bean plants. Controlled variables? Ah . . . I suppose you'd want to control the amount of sunlight, the control of water, have a "control" like normal sunlight, normal water and see how it differs with plants with like little or some or more sunlight and water.

I What does it mean to control . . . what are you doing when you attempt to control variables in an experiment?

S Ahm you mean like to control variables?

I Yeah, I'm trying to get at you know, what does it mean in this experiment to have the variables controlled?

S I suppose if you want control over the variables like, okay . . . like the amount of growth and the effect of this on ah . . . (indefinite pause).

I What would be some variables you would control in this experiment on "the effect of sunlight on the growth of bean plants"?

S Okay, the sunlight.

I How would you control sunlight?

S I'd control sunlight by having like plants closer to the window, far away from the window, no light at all, more light than others (more hours of light).

I So how would that be controlled? You would be actually controlling it?

S Yes.

I What other controlled variables would you have?

S Ah water. Little water, no water, too much water.

I What else?

S Ahm . . . I don't really know what you mean. Controls? Like are you talking about like me or what I'd do or . . .?

I What I'm trying to get at is your understanding of it, okay?

S Yeah. I don't know.

I Alright, let me ask you this then. What variables would you try to keep constant throughout this experiment?

S Well, I. . . .

I Keep the same or constant throughout the experiment.

S Well, I don't really know what you're getting at but like you'd have a control sort of. That's kind of like a plant in the house you know, and how it should develop and how it should grow in normal sunlight and normal water. Then you'd have the other ones that like vary in degrees of more or less water and sunlight. What was the question again?

I I said, what variable in this experiment would you keep constant?

S The sunlight and the water; you wouldn't be able to change them I guess.

I Why is it important to control variables in an experiment?

S Well, so that the answer would be valid I guess.

I Okay, would you like to explain that? Why would the answer be valid?

S Well, if you're trying to understand what will happen to a plant if there's less water or less sunlight and you change the variables, like you add more sunlight and more water, like the answer is not going to be valid.

I So why wouldn't it be valid?

S Because it's changing. Because it's not . . . (indefinite pause).

I What is an inference statement?

S I have no idea.

I What does it mean to infer something? To make an inference?

S Infer ahm . . . I guess infer . . . that's kind of like ah . . . I don't know. A round-about way of saying something I guess. Could you ask the question again?

I Okay, I just said "what does it mean to infer, to make an inference"?

S (Long pause).

I Is there a difference between inferring and observing, or are they basically the same?

S Ah they're different.

I So how are they different?

S Inferring is kind of like you "think" it's gonna happen so you write down, "OK I think this is gonna happen." And an observation is like you observe like the rate of growth. "Like it's definite." But inferring is not. It's your ideas.

I In your mind, what is an observation?

S Okay, it's the results of an experiment as seen or smelled or touched or tasted or things like that.

I Here is another six statements and I want you to tell which are observations and give your reason why.

S Okay, the first one's an observation.

I Why?

S Because it tells what's going on. It's not like your ideas of what's going on. It says "has a strong choking smell."

I Okay, the second one?

S Observation as well.

I And the reason why?

S Because it . . . it don't say "I think" the chemical used is a yellow powdery substance, or "should be" a yellow powdery substance. "It is" a yellow powdery substance.

I Number three?

S (Pause). I think that one is not an observation.

I Why isn't it?

S Well, it wouldn't be seen so you can't observe it.

I So what about number four?

S Observation because where they were added together, there was a hissing noise. It was observed, it was noticed.

Number five is an observation as well because it felt sticky. It wasn't "it should feel sticky" or . . . the way it's stated.

I Okay, number six?

S I don't think that is an observation because you can't really tell that by looking at the experiment.

I What does it mean to interpret data?

S That's your idea of what's been going on in the experiment.

I Anything else you'd like to add to that or. . .?

S It's based on scientific ideas I guess.

I Look at Table 1 and make one summary or concluding statement about what the table is saying.

S Okay, the more water a plant receives in the given amount of time, the greater the rate of growing in the plant.

I How about Table 2?

S The more of study time directly influences the rate of achievement. So the more you study, the higher your marks.

I What is a prediction?

S That's ah a statement before . . . a statement given in an experiment before you really know what's going to happen. It's an idea on. . . . I guess that's it.

I Is there a difference between a prediction and a hypothesis, or are they the same?

S Yes, there is a difference.

I Okay, so what is it?

S A hypothesis is based on scientific findings. It's kind of like what you believe will happen. But a prediction is kind of like what you think is going to be the end result.

I Okay, I'm not sure if I know the difference here.

S A hypothesis you make at the beginning of the experiment.

I So a hypothesis is what? What did you say it was?

S I can't remember (pause). Okay, it's an educated guess before the experiment is begun.

I And a prediction is what?

S It's the predicted outcome of the experiment half way through or at the end, not at the beginning.

I So how are those two different now then?

S Okay. Hypothesis, well that's an educated guess and a prediction is your . . . what you think is going to happen like at a different time, like later on in the experiment.

I Here is Table 1 again. Assume a sixth plant and it was given 18 ml of water a day. What do you think the height of the plant would be after two weeks?

S It would be around 29 or 30 cm.

I So how sure or how certain can you be about that?

S Because like the rate is about 5, 5 ml and it grows 4 cm, 10 ml and it grows 15 cm. So what I did was, okay 18 is just about fairly in between 15 and 20. So I counted 27 and 32 and I took the reasonable middle of the numbers.

I What if the sixth plant was given 35 ml of water a day. What do you think the height would be after two weeks then?

S Forty-nine centimeters.

I Which prediction are you most certain about, or are you just as certain about both?

S I think I'm more certain about the first one.

I And the reason why?

S Well, I think you can be more accurate because it's like less . . . there's like less. . . . Ah the numbers are smaller and therefore there's a greater margin of ah . . . I don't know. I just felt this one's more valid and the second one's more . . . (indefinite pause).

I Okay. See if you can collect your thoughts now and see if you can give me a reason why you think the first one is more valid, why you feel more certain of the first one than the second one.

S Well, I know both the effect of before and after what happened. So I can use them based like in between both of them is like what 18 ml will bring. This is like 35 ml. You don't know what's gonna happen after 35 ml. You don't really know if it's gonna shoot up or get worse or, you know.

I Now in Table 1, what variable would the amount of water per day be? Would it be a controlled variable, an independent variable, or a dependent variable?

S It's not a dependent variable. I guess it would be a controlled variable.

I Okay, why would it be a controlled variable?

S Or independent. Ah. . . .

I It would be controlled because what?

S Because of the different amounts. You control the different amounts of water the plants use.

I Okay, what would this be: "the growth of the bean plants"? Is it a controlled, independent or dependent variable?

S Dependent.

I Why is it dependent?

S Because it depends on the amount of water for how much the plant will grow.

I So what would be some other variables you would control here?

S The amount of sunlight, temperature . . .

I Amount of sunlight meaning what? What would you do with each plant?

S Okay, for the amount of sunlight I'd have plant one, two, three, four, and five and a number of hours of sunlight or closest to the window and you know.

I So would you give one plant . . .?

S As much as possible.

I And the next plant?

S A little less and a little less and so on.

I And at the same time you're giving them less and less water or more and more water?

S Mm mm (nods head to signify yes).

I Why is it important to control variables, to have control of variables in your experiment?

S Well, if you don't have control of the variables, the answer won't be valid because you're trying to find out the different effects of . . . there's different amounts of water and sunlight. And if you don't have control over it, then you could have different amounts, but you know they'd be varied. And the answers won't be valid.

**Sample Conceptual Inventory: Group D (Subject 32, School 16)**

**A) EXPERIMENTING**

***1.0 Planning an Experiment Involves:***

1.1 deciding how the experiment will be done.

1.2 selecting the materials to be used.

1.3 determining the location of the project.

1.4 setting up a "control" to compare the results to.

**B) HYPOTHESIZING**

***2.0 A Hypothesis is:***

2.1 a statement about an experiment prior to having a conclusion about it. It is an educated guess about what the outcome of an experiment will be.

***3.0 Identifying a Hypothesis:***

3.1 Statements containing words of uncertainty like **"should"**, **"probably"**, or **"likely"** are hypotheses because they are guesses of what might happen.

3.2 Statements with the word **"will"** in them are not hypotheses because these statements suggest that the experimenter already knows the outcome of the experiment. These statements are conclusions, not hypotheses.

3.3 Statements that are definite are not hypotheses.

**C) IDENTIFYING AND CONTROLLING VARIABLES**

***4.0 Listing Variables:***

4.1 (Subject listed several variables that were relevant to the experiment being discussed).

***5.0 Independent Variable:***

5.1 An independent variable is one that is not influenced by the experiment.

5.2 An independent variable is one that is the opposite of the dependent variable.

5.3 There is no set number of independent variables in an experiment, but there should be the smallest number possible.

5.4 An independent variable is the same as a controlled variable because neither of them are dependent on the experiment, and both are controlled by the experimenter.

*6.0 Dependent Variable:*

6.1 A dependent variable is one that depends on the independent variable.

6.2 There should only be one dependent variable in an experiment.

6.3 A dependent variable is not the same as a controlled variable because it depends on the controlled and independent variables in an experiment.

*7.0 Controlling Variables:*

7.1 Controlled variables are those that the experimenter has full control over during an experiment. He or she decides how these variables will affect the experiment.

*8.0 Importance of Controlling Variables:*

8.1 If variables are not controlled, the results of an experiment will not be valid.

**D) INFERRING VERSUS OBSERVING**

*9.0 Inferring:*

9.1 is just a round-about way of stating your ideas.

9.2 is not the same as an observation because inferring is thinking what will happen; it's not definite. Observing is more definite than inferring; it states exactly what is noticed.

***10.0 Observing:***

10.1 **An observation is the results of an experiment as seen, smelled, heard, touched, or tasted.**

***11.0 Identifying Observations:***

11.1 **Only those statements that describe exactly what has happened to the objects in an experiment are observations.**

11.2 Statements with words like **"I think"** or **"should be"** represent someone's ideas, and are therefore not observations. Observations are definite statements of fact containing words like **"it is."**

11.3 Statements providing reasons or explanations for what has been noticed are not observations.

**E) INTERPRETING DATA**

***12.0 Interpreting Data Involves:***

12.1 expressing your ideas on what has gone on in an experiment.

***13.0 Ability to Interpret Data:***

13.1 (Subject easily interpreted the data in Tables 1 and 2).

**F) PREDICTING**

***14.1 A Prediction is:***

14.1 a statement of what the outcome of an experiment will be. This statement is not given at the beginning or end of an experiment, but somewhere in between.

14.2 **not the same as a hypothesis because a hypothesis is an educated guess based on scientific findings, and is given at the beginning of an experiment. But a prediction is what you think will happen in an experiment, and is given after the experiment has started but before it ends.**

## *15.0 Interpolating Versus Extrapolating:*

15.1 Interpolating is safer than extrapolating because there is more data there to guide you.

15.2 Extrapolating is more uncertain than interpolating because it goes beyond the available data.

## Appendix C

**Instructions Distributed to Graduate Students in Efforts to Validate the Conceptual Inventories Used in the Study**

**Letter of Instructions to Graduate Students**

The information package you have been given concerns a study that is currently being conducted to ascertain student understanding of "science process skills." In the spring of 1989, 32 students were interviewed and asked a series of questions related to some of the more common science process skills. All interviews were tape-recorded and then transcribed on paper. After this was complete, a conceptual inventory was developed for each student based on the "student ideas" contained in the transcript. This involved carefully reading the transcripts and then representing the students' conceptions in the inventories.

In the next phase, information in the conceptual inventories will be carefully analyzed to identify student misconceptions. Therefore, it is extremely important that the conceptual inventories be very accurate. It is hoped that you will assist in determining the accuracy of these inventories by reading the transcripts in the package, and then deciding if the ideas in the respective inventories have a basis in the transcripts. If you feel some ideas have been omitted, you are asked to include them on a separate sheet of paper. At the same time, if you feel some of the ideas contained in the inventories do not have a basis in the respective transcripts, you are asked to identify them on a sheet of paper and, if desired, you may also provide reasons for your decisions. Note that the ideas in the inventories have been numbered to correspond to the places in the transcripts where the ideas were obtained.

Included in the package are the lists and tables used during the interview sessions. Referring to the lists and tables will sometimes assist you in determining where some of the ideas in the inventories were obtained. This is particularly true for the sections concerned with identifying hypotheses and observations.

In general, you are asked to help establish the accuracy of the conceptual inventories by identifying the items that should be omitted or added to them.

Thank you for your time and cooperation.