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Inquiry and inscription as keys to authentic science instruction and assessment for preservice secondary science teachers

Boyd Edward Lunsford
University of Tennessee

To the Graduate Council:

I am submitting herewith a dissertation written by Boyd Edward Lunsford entitled "Inquiry and inscription as keys to authentic science instruction and assessment for preservice secondary science teachers." I have examined the final electronic copy of this dissertation for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Education, with a major in Education.

Claudia T. Melear, Major Professor

We have read this dissertation and recommend its acceptance:

Accepted for the Council:

Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

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Vice Provost and Dean of
Graduate Studies

INQUIRY AND INSCRIPTION AS KEYS TO AUTHENTIC SCIENCE INSTRUCTION AND ASSESSMENT FOR PRESERVICE SECONDARY SCIENCE TEACHERS

A Dissertation
Prepared for the
Doctor of Education
Degree
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Boyd Edward Lunsford
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Abstract

This research project consists of a qualitative study of a group of preservice science teachers who, at the time of the study, were enrolled in a graduate level course designed especially to acquaint them with the skills of doing and teaching science by way of scientific inquiry. Most students in the study held bachelor's degrees in some aspect of science, mostly biological sciences. The students were evaluated in the course by way of authentic assessment techniques, including the scientific inscriptions they constructed as they carried out their inquiry activities. The students constructed more than 1500 inscriptions in the course and used them in appropriate ways. Evidence suggests that an inscription rubric, based on criteria used by professional scientists in the ways they make and use inscriptions, and explicit instruction about inscriptions in professional science helped students maximize their use of inscriptions. The students showed an understanding of the importance of a well-prepared inscription and of the collaborative, social nature of authentic science. During the study, the researcher concluded that the students entered with poorly developed skills relating to the Nature of Science and Process domains of Science Education. The students completed several inquiry projects and learned a variety of content, laboratory skills and scientific processes. The students said they believed that the authentic assessment techniques used to evaluate their work were more valid than traditional paper and pencil tests. The students' ability to design and carry out successful experiments over time improved during the study. They attributed this to participating in inquiry and in maintaining inscriptions related to their work.

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Glossary

Apprenticeship:

A socially based learning situation or context in which a novice or unskilled individual works with a person who has mastered a particular craft, skill or occupation. The skilled person allows the novice to actually practice various aspects of the craft within the novice's zone of proximal development (see below) as mastery is achieved.

Authentic assessment:

Grading practices and techniques that are consistent with learning activities and desired outcomes. For purposes of this study, authentic assessment includes those techniques typically used to assess the work of professional scientists.

Authentic science:

See Open Inquiry, below.

Ceratopterius richardii:

Scientific name for the species of fern which includes the cultivar known as C-Fern™. (Synonym = *C. richardii*)

C-Fern™: A cultivar (see below) of the fern *C. richardii.*

Constructivism:

A theoretical paradigm resting on the assumption that knowledge and reality are built by thinkers rather than existing independently of thinkers.

Control Group:

In a traditional scientific experiment, that group against which the experimental group (see below) is compared to determine if evidence exists to support a hypothesis. [Synonym = control]

Corn Flake:

Participant term for the hermaphroditic C-Fern™ gametophyte.

Cultivar:

A distinctly recognized genetic variation of a plant species that is cultivated or grown, often for commercial use.

Durante:

Participant term for the young C-Fern™ sporophyte as it emerges from the gametophyte.

Experimental Group:

In a traditional scientific experiment, that group which receives some specific experimental variable or treatment. It is compared against the control group (see above) to determine if evidence exists to support a hypothesis.

Fiber optics:

Participant term for the emerging roots on the C-Fern™ sporophyte.

Formative Assessment:

A form of evaluation that takes place during a learning task or activity. It may or may not involve quantification. The primary goal of formative assessment is to give the learner useful feedback in an effort to enhance learning in progress.

Gamete:

Cell used for sexual reproduction. Following fertilization, the male and female gametes produce a zygote, which in plants and certain other organisms may give rise to the sporophyte.

Gametophyte:

That phase, or those structures, of a plant's life cycle that produces gametes.

Green:

Participant term for the wild type gametophytes of C-Fern. (see "Saint Patrick's Day Corn Flake" below)

Guided Inquiry:

A variation of inquiry (see below) in which the scientific work performed by students is modified or restricted to be less like open inquiry (see below). These modifications or restrictions may include, but are not limited to, making the activity of shorter duration, making it focused on more specific objectives or skills or having the research deal with predetermined research questions or methods. (Synonyms = Purposeful Inquiry, Structured Inquiry)

Inquiry:

A pedagogical practice for teaching science involving scientific experimentation, observation and other practices consistent with actual scientific practice. (Synonym = Scientific Inquiry; Compare with Guided Inquiry and Open Inquiry)

Inscriptions:

Written, electronically, or otherwise stored representations of scientific knowledge. Examples may include maps, equations, diagrams, charts, graphs, photographs, concept maps, written descriptions and tables of data.

Mealworm:

Common name for the larval state of certain beetles in the genus *Tenebrio* which tend to feed on stored grain.

Mediated Learning Experience:

A variation of apprenticeship (see above) within social constructivism (see below) in which a skilled mediator helps a learner to most effectively approach a learning task or problem by helping the learner to formulate and carry out effective cognitive plans. Also, the mediated learning experience has the goal of helping the learner transfer these plans and skills no novel situations.

Metamorphosis:

Process of undergoing dramatic changes in shape or lifestyle during the life span. Many types of insects and other organisms undergo metamorphosis.

Nature of Science:

Those methods, processes, skills, interactions and techniques involved in professional scientific practice. For purposes of this study, the nature of science includes the assertion that scientific knowledge is tentative and subject to change, that it is not an authoritarian discipline and that social practices among scientists influence their activities.

Open Inquiry:

The most pure form of inquiry (see above) in which students work in ways that exactly, or nearly exactly, duplicate the work of professional scientists. (Synonym = Authentic Science; Compare with Guided Inquiry, above)

Operational Definition:

In a traditional scientific experiment a clear and precise characterization or description of a treatment, measurement technique or variable that must be known in order for the experiment to be repeated or evaluated by others.

Ovum:

The female gamete or sexual reproductive cell. (Plural = Ova)

Polka Dot:

A genetic mutant of C-Fern™ in which chloroplasts cluster in clumps.

Positivism:

A theoretical paradigm resting on the assumption that knowledge and reality exist as independent entities and that they are discovered by way of research.

Process of Science:

Those methods by which scientific practices are performed. They include how experiments are designed, how observations are done, how data are gathered and evaluated and how conclusions are made.

Replicates:

In a traditional scientific experiment, the number of times a specific procedure or experimental design is repeated. In general terms, a larger number of replicates allows for more certainty when evaluating results and determining conclusions.

Rice:

Participant term for the male C-Fern™ gametophyte. (Synonym = Rice Crispy)

Rubric:

An evaluation or grading tool consisting of a list of expected behaviors or criteria along with point values for the various levels at which the behaviors or criteria may be performed.

Scientific Inquiry:

See "Inquiry" above.

Saint Patrick's Day Corn Flake:

Participant term for the hermaphroditic gametophytes of the polka dot genetic mutant (see above).

Sample Size:

In a traditional scientific experiment, the number of organisms (or cases) used in an experimental and/or control group (see above). In general terms, a larger sample size allows for more certainty when evaluating results and determining conclusions.

Social Constructivism:

A variation of the theoretical paradigm of constructivism (see above) which emphasizes the role of groups of thinkers in constructing knowledge and reality.

Spermatozoon:

The male gamete or sexual reproductive cell. (Plural = Spermatozoa)

Spiral:

Participant term for the C-Fern™ spermatozoon. (see above; Synonyms = squiggle, squig)

Squig:

See "spiral" above.

Squiggle:
See "spiral" above.

Spore:
Cell used for asexual reproduction in many plants and in certain other organisms. Following germination, they may give rise to the gametophyte.

Sporophyte:
That phase, or those structures, of a plant's life cycle that produces spores (see above).

Summative Evaluation:
A form of assessment, most commonly called grading, that takes place at the conclusion of an activity or learning task in order to determine and often quantify success or failure.

Treatment:
In a traditional scientific experiment, the specific manipulation applied to the experimental group (see above) but not to the control group (see above). This allows the two groups to be compared to determine if there is evidence that the manipulation has caused some difference between the two groups.

Zone of Proximal Development:
The limited range of thinking and ability of a student, within which apprenticeship learning or mentoring may successfully take place. (See Apprenticeship, above)

Chapter One: Introduction

Overview

Over the last several years there have been numerous calls to begin reforming the ways by which science students, at all levels, are taught and evaluated. It appears that the dissatisfaction with traditional methods of science instruction is not new, however. For as early as 1859 Herbert Spence, a British philosopher, complained that science instruction was characterized by the passing of a collection of "dead facts" to students with no emphasis on how science may be relevant to their daily life and welfare (Hurd, 1998).

At the core of many of the reform recommendations is the assertion that science students should be engaged in the sorts of activities that parallel those of professional scientists. Specifically, the reform recommendations call for widespread use of scientific inquiry as a method of learning science content, as well as for the use of more authentic assessment techniques (American Association for the Advancement of Science (AAAS), 1990; National Research Council (NRC), 1996; National Science Teacher's Association (NSTA), 1996; NRC, 2000). This approach to science instruction is rooted in the philosophy of learning known as constructivism, the belief that individuals build or construct their knowledge based on their experiences. Also, the social constructivist movement is central to this approach. In this variation of constructivism, the attention is focused on how knowledge is built within episodes of social interactions with learning groups (Guba, 1995; Mezirow, 1996; Baker & Piburn, 1997; Duit & Treagust, 1998; Staver, 1998). The remainder of this chapter will describe and provide an overview of this research project.

Statement of the Problem

Instruction by way of scientific inquiry and the use of authentic assessment techniques clearly do not appear to be widespread practices in science education. In fact, even many preservice science teachers, from elementary to high school levels and probably beyond, appear to hold deep resistance concerning the practicality, and even the usefulness, of scientific inquiry as a pedagogical practice (Eiriksson, 1997; Melear, Goodlaxson, Warne & Hickok, 2000).

Need For the Study

Comparatively little research has been done concerning how scientific inquiry may be assessed. Most of the available research focuses on the more traditional, paper and pencil tests or on standardized tests that resemble them (Slater, Ryan & Samson, 1997; Zachos, Hick, Doane, Sargent, 2000). There is clearly a need for additional research involving situations in which inquiry and authentic science assessment is the norm, rather than the rare exception. These situations need to be documented, explored and considered in terms of the science education reform recommendations previously noted.

Purpose of This Research

This research study is focused on a classroom in which students learn science through scientific inquiry and are evaluated by the use of authentic assessment techniques, including the scientific inscriptions they generate as they study science. Scientific inscriptions are written, photographic, electronic or otherwise recorded representations of scientific observations and scientific thinking. They hold potential as authentic assessment tools when coupled with scientific inquiry (Latour & Woolgar, 1979; Roth & McGinn, 1998). Further, scientific inscriptions are strongly related to the natural phenomena they represent (Kozma, Chin, Russel & Marx, 2000). In other words, a graphical inscription showing the relationship between soil moisture and fungi population levels would have been derived from detailed study and observation of those two factors. More details on scientific inscriptions are provided for the reader in Chapter Two.

Because science classes that predominantly utilize scientific inquiry and authentic assessment are still atypical, questions dealing with both assessment and the general nature of the teaching and learning practices in such an environment will be considered.

Research Questions

The following questions are specifically addressed in this research project. (1) What are the experiences of students who learn science through inquiry? (2) What are the experiences of students who are assessed by authentic techniques? (3) What are some examples of scientific inscriptions students record during their experiences? (4) Will participation in an inquiry-based science course, and in the activity of recording inscriptions, improve students' ability to design and carry out successful science experiments over time?

Assumptions

The data used in this investigation come heavily from the artifacts generated by a group of graduate students who comprise the research population. It is assumed that this heavy emphasis on the students' actual words, experiences and outcomes represents a sound method of data collection. This methodology is widely used in qualitative research and is consistent with the social constructivist paradigm (Denzin, 1988; Jorgensen, 1989; Guba, 1995).

Limitations

At the beginning of this study, research participants were specifically asked to refrain from doing library based research, internet research or a literature review on a specific organism, a cultivar of *Ceratopteris richardii*, known as C-Fern™, during approximately the first eight weeks of the study. It is assumed that the research participants complied with this request. Further, it is assumed that all participants responded accurately, fully and truthfully in all their written and oral communications concerning their experiences.

Researcher Bias

The author is of the opinion that all research, even the most tightly controlled double blind experimental study, is subject to researcher bias. Bogdan & Bilken (1997) note that qualitative researchers should seek to limit but not eliminate their predetermined ideas and other sources of bias by acknowledging that they exist. With that in mind, the author will disclose that he has been heavily influenced by the social constructivist paradigm and that he strongly believes in the value of scientific inquiry as a tool by which to learn science. Further, the author strongly believes that an understanding of the nature of science is sorely lacking among most adults, even among science majors at the university level. He also strongly believes that participation in scientific inquiry will influence one's beliefs about the nature of science.

Summary

This chapter has presented a very general overview of the research study at hand. This research study represents a qualitative investigation of a classroom in which students were taught primarily by scientific inquiry and assessed partly through scientific inscriptions. In the following chapter, Chapter Two, a review of the literature will be presented.

Chapter Two: Review of Literature

In the previous chapter, Chapter One, a brief overview of the problem addressed by this research study was presented. Four primary research questions were listed. This chapter, Chapter Two, will include a review of the literature most pertinent to the research study. Specifically, a review of social constructivism and science education reform recommendations important for this study, including inquiry, will be detailed. Finally, a review of scientific inscriptions and authentic assessment will be included.

Social Constructivism

The philosophical and educational paradigms known as social constructivism are at the heart of the educational reform recommendations dealing with the teaching, learning and assessment of science. Because social constructivism forms the underpinning of the methodology for this research project, a consideration of social constructivism is necessary.

In very general terms, social constructivism theory stands in sharp contrast to traditional positivist theories that have dominated scientific thinking for so long. The social constructivist views reality as relative, the product of possibly multiple mental viewpoints. In short, reality is constructed rather than discovered (Guba, 1995; Mezirow, 1996; Staver, 1998). In more practical terms, social constructivism focuses heavily on the social aspects of building knowledge (Duit & Treagust, 1998) and frowns upon any system that fails to empower all voices (Baker & Piburn, 1997). The social constructivist would assert that knowledge is not passively received but built by the thinker(s). Language gives rise to meaning for the individual and the community of which he/she is a part (Staver, 1998). Finally, culture is seen to drive intellectual development (Baker & Piburn, 1997) as cultural situations help to make a constructed knowledge base. This idea is known as situated cognition (Duit & Treagust, 1998).

The term "situated cognition" implies that one is thinking within a context. Psychologists and the general public have probably considered how a person thinks since the dawn of time. However, it was the Swiss psychologist, Jean Piaget, who is credited as being the main founder of cognitive psychology in an academic sense. Piaget had a background in biology. He proposed that a child's ability to think, use logic and reason developed through a series of stages. Piaget coined the term "schema" to describe the mental plans a person develops and uses to make sense of the world. From a philosophical standpoint, Piaget also heavily emphasized the notion of a priori (before the fact) knowledge. He believed that some valid knowledge existed without benefit of formal tests and one's sensory experiences. As scientists began to evaluate Piaget's work, many of them found fault with his theories. They remained interested in his general notion of cognition (Baker & Piburn, 1997) but believed that he ignored the contexts within which schema developed and failed to note variations in cognition from situational standpoints (Duit & Treagust, 1998; Staver, 1998). In time, many scientists began to supplement Piaget's basic theory with the work of others.

Perhaps the key figure in the development of social constructivism was Lev Semenovich (L. S.) Vygotsky, a psychologist from the Soviet Union who lived from 1896 to 1934. Vygotsky focused heavily on the role of culture, society and history in knowledge development (Mezirow, 1996; Baker & Piburn, 1997). Glassman (2001) noted an unusual interplay between the work of Vygotsky and that of the educational psychologist John Dewey in the zeitgeist of Soviet politics. Dewey's theories were similar to Vygotsky's in many ways. However, as Glassman reports, Dewey focused more on the individual while Vygotsky was concerned with the society. This notion seemed to fit well within Soviet political philosophy. Dewey's ideas were condemned and Vygotsky's were (at least for a time) allowed to flourish.

A few key points of Vygotsky's theory are worthy of more detailed discussion. First, he saw the education of students as being essentially in the hands of an adult who served as a sort of mentor and representative of society. The adult's job was to create opportunities for learning that were socially, historically and culturally relevant. He or she was to actively guide the child's thinking by formulating doubt and the need to learn. In short, the child would work within a "zone of proximal development" with the adult mediator as learning took place (Glassman, 2001). The adult's role may best be thought of in terms of a master craftsman and the child's as an apprentice. The child (or more generally, the student) actively participates within the master's world of practice and is thereby acculturated into that world (Farnham-Diggory, 1994).

The psychologist Reuven Feuerstein has expanded upon the role of the teacher or adult within the zone of proximal development with his theory of mediated learning experience. He has also developed a program known as Instrumental Enrichment. The goal of this program is to provide learners with metacognitive learning strategies that enhance their ability to learn (Feuerstein, Rand, Hoffman & Miller, 1979). A basic summary of Feuerstein's program, presented by the Southeastern Center for the Enhancement of Learning [http://www.scel.org/feuersteinie.html], is available on line. Further, a program developed by Greenberg (2000) expands upon Feuerstein's work. This program also focuses on helping the learner to acquire effective thinking strategies by way of mediated learning experiences. The program emphasizes an inquiry based learning format and the social construction of knowledge. The program may be used across most any academic discipline or learning situation.

Social Constructivism and Professional Science

Many people probably regard science as a highly objective, sterile practice that would, in no way, parallel the social constructivist view of reality. However Latour and Woolgar (1979) presented an ethnographic study of scientists and technicians that seriously challenges this view. In this seminal study the authors spent months observing scientists and technicians at work in a microbiology laboratory. The research study they completed was unique in that Latour and Woolgar placed a heavy emphasis on sociological interactions among the professional scientists in the laboratory. In fact, they set out to study the social culture of the lab participants. They assert that scientists really do operate within what Lave and Wenger (1991) would call a community of practice. In fact, Latour and Woolgar (1990) called science a "disordered array of observations with which scientists struggle to produce order" (p. 36). They noted that scientists typically work and think together, within small and large communities of practice, to construct reality, meaning and what we often refer to as "fact." What constitutes a fact is, in professional science, largely a matter of consensus of opinion. This notion contrasts sharply with the traditional idea that a fact is an independent thing, which waits to be discovered by an objective scientist. A "fact" may be rejected at first but later embraced and accepted with repeated research and publication (Latour & Woolgar, 1979; Lynch, 1985; Kusch, 1999).

Since Latour and Woolgar's groundbreaking study (1979) a string of similar sociological studies of science and scientists have appeared. Physicists, astronomers, geneticists, chemists and others have been observed from the vantage point of the social scientist. A few studies will be mentioned in this review. Garfinkel, Lynch and Livingston completed a study of professional astronomers in 1981. Their study echoed Latour and Woolgar's assertion that scientific knowledge is socially constructed. Lynch (1985) completed a social study of the science of neurobiology. In this study Lynch admitted that much of the knowledge of the scientists involved in the study was socially constructed. He likened the "science talk" among the participants to negotiations of what constituted truth and objectivity. Lynch was, however, reticent to generalize this notion widely to other areas of science. Latour (1987) completed a study of scientists and engineers and noted that scientists work as a group to refine and consider their results. Knorr-Cetina (1999) presented sociological studies of molecular biologists and physicists. She also asserted that scientific facts are constructed, rather than objectively discovered. Kusch (1999) reported a similar theme among professional psychologists, noting that they also operate and construct their disciplinary knowledge within a social arena. Traweek (1988) studied physicists in Japan and in the United States of America. She presented additional evidence that knowledge within the discipline is constructed, not objectively discovered.

Aside from the numerous studies that focus on a well-defined cultural group in various scientific disciplines, a few other things are of note. Culture, it seems, may extend beyond the doors of a laboratory. Barnes and Bloor (1996) noted the role of experience in helping a scientist gain credibility and prestige within his or her profession. They further noted that this credibility might often give the scientist a higher relative ranking within their larger professional social group. Even cultural and political practices and beliefs may influence what a scientist studies and how they utilize their findings. The role of politics and culture is evident in funding, publication and other aspects of professional science (Rouse, 1987). Also, Traweek (1988) noted that, among professional physicists, women are overtly in the minority. Another interesting general argument about the collaborative, social nature of professional science is that more than 95% of scientific research papers are produced by more than one author. In fact, the twelve most cited studies in 1998 had an average of more than five authors (Hurd, 1998).

<u>Social Constructivism and Science Education</u>

As noted above, social constructivism is at the heart of a number of research and reform issues in science education. Both AAAS (1990) and NSTA (1996) stressed the need to model science instruction on the involved social activity that "real" science actually is. A number of research reports will be explored to argue that these reform recommendations are well founded.

Lave and Wenger (1991) considered several ethnographic studies of learning within social contexts. These studies focused primarily on the role of apprenticeship in situations as diverse as midwifery among native peoples in the Yucatan Peninsula, and work practices of supermarket butchers in the United States and tailors of clothing in Liberia. At the heart of Lave and Wenger's findings is the notion that meaningful learning most often occurs within the context of an intricate "community of practice." The members of the community range from novice/newcomers to "old-timers." The master-apprentice relationship is characteristic of the social climate in terms of learning. Further, the authors argue that the learning that occurs within such situations is not a matter of mere passive observation, but of "legitimate peripheral participation" within the community of practice. In short, the apprentices do real work, in real circumstances, as they advance toward mastery of the craft or skill in question. They take part in ever more complex activities relating to their goal. They are given opportunities, resources and guidance in order to do so. They learn the language, skills and tacit knowledge of the practice.

Several writers have noticed the sharp contrast between traditional science instruction in schools and the work of professional scientists (Lave & Wenger, 1991; Roth, 1995; Roth, et al., 1998; Bowen & Roth, 2000). They have noted that traditional science instruction, in fact, does not even begin to approximate actual scientific practice until graduate school (Lave & Wenger, 1991; Roth, 1995).

W-. M. Roth has presented tremendous evidence that school-based science instruction can mirror the social circumstances in which scientists actually do their work. Roth (1995) prefers to call this approach "open inquiry" or "authentic school science." His approach, arguably, could be included in the sort of "community inquiry" advocated by science education reformers (NSTA, 1996). Roth's goal for science education is to create a "learning rich environment" in which students work together (and work with the teacher) to manipulate real scientific apparatuses to solve real scientific problems. The students design their own methods, formulate their own questions and use their previous work to direct their future work (Roth, 1995). Further, the students negotiate the validity of their findings with other members of the community of science (both inside and beyond the classroom) (Bowen & Roth, 2000). Other researchers have emphasized the need for collaborative work among science students, which stresses understanding of the process skills of science. Central to this is the ability to generate and answer useful and interesting questions and to understand the need for scientific claims to be critiqued by peers (Blumenfelt, Marx, Soloway & Krajcik, 1996).

Overview of Scientific Inquiry as a Pedagogical Practice

Numerous organizations and individual researchers have advised that science teachers should include inquiry-based science instruction in their science courses, at all educational levels (AAAS, 1990; NRC, 1996; NSTA, 1996; Crawford, 2000). With such a heavy emphasis on inquiry (more properly known as "scientific inquiry") in place, it is immediately necessary to describe the characteristics of inquiry as a pedagogical practice and as a mode of learning.

Scientific inquiry, as a pedagogical practice, is rooted in the social constructivist paradigm. The basic idea behind inquiry-based instruction is that students should be allowed to engage in the sorts of activities that professional scientists are actually involved in. In short, the philosophy of inquiry-based instruction is that the science classroom should mirror the scientist's domain (AAAS, 1990; Roth, McGinn & Bowen, 1998). Several types of inquiry, all of which are variations on a few basic themes, are recognized.

The purest form of scientific inquiry in the classroom has been called "authentic science" or "open inquiry" (Roth, 1995; Ritchie & Rigano, 1996). This technique rests on the premise that science is routinely done as teamwork and that scientists generally direct their own thinking. During open inquiry, students formulate their own questions and problems for possible research. They revise and reconsider these questions as they work. The students formulate their own methods and data collection/analysis procedures as they work within the immediate classroom community and the larger scientific community (Roth, 1995). To further characterize the process one should note that classroom communities involved in open inquiry are actively engaged in a search for "answers." The students may consult published scientific materials to review what is known. They make predictions, interpret data and consider alternative evidence or hypotheses (AAAS, 1990; NRC, 1996). The students come to understand scientific phenomena through their work. They look for cause and effect relationships. They measure things and use various other types of scientific equipment (Zachos, Hick, Doane & Sargent, 2000). They test their hypotheses by way of controlled scientific experimentation (Germann & Aram, 1996). In short, the students work together (and with their teacher) to actually "do" science. To emphasize the social constructivist interactions that characterize the activity of open inquiry, some writers have called the process "community inquiry" or "collaborative inquiry" (NSTA, 1996). This method stands in sharp contrast to what some writers have called "cookbook science" in which students verify previously known concepts with little more understanding than would be involved in following the step by step instructions of a recipe (Roth, 1995). There is a tendency for teachers utilizing such "cookbook" activities to oversimplify the experiment or activity and to neglect emphasizing the process skills of science. In some cases, students often tend toward falsification of results in such activities in an effort to arrive at a correct or expected answer (Fairbrother, Hackling & Cowan, 1997).

As previously noted, variations on the basic open inquiry model have been described. Some writers have suggested the terms "guided inquiry," "purposeful inquiry" or "structured inquiry" to describe such variations. Such inquiry sessions may be of shorter duration, for example. Also, the teacher may design these sorts of inquiry activities to address specific content goals or objectives. They may provide students with a research question or with specific laboratory materials (Foster, 1998; Zachos, et al., 2000). The basic idea is the same in that, whether working alone or together, the students carry out activities that a professional scientist might engage in. The science they do is authentic.

Scientific inquiry, as a pedagogical practice has many advantages and desirable outcomes. It is not, however, recommended as the only method one should use to teach science (NRC, 2000). There is clearly a need for more specific and detailed study about the benefits and/or drawbacks of inquiry-based instruction. This section will briefly review some existing recommendations on the use of inquiry. Pursuant to that, Enger and Yager (1998) have reminded us that good science instruction has many dimensions. It should include not only the facts and content of science (the Concept Domain) but should allow students to understand how science and scientists actually work (the Nature of Science Domain). Students should be allowed design experiments and test their own hypotheses. They must measure, manipulate variables and apply their previously acquired knowledge in new situations. These are aspects of the Process, Attitude, Application and Creativity Domains of science.

Inquiry is probably not the method of choice if one's primary goal is for students to memorize bits of factual information. Also, specific scientific protocols, use of potentially dangerous materials or equipment, and basic safety issues are probably not candidates for being taught through inquiry (NRC, 2000). If, however, one's goals are rooted in other aspects of scientific literacy, then inquiry-based instruction holds promise.

As a formal teaching methodology, inquiry first began to be widely implemented in the 1960's. Some of the curricula from this era were more consistent with today's definition of inquiry than were others (NRC, 2000). In a major meta-analytic study Shymansky, Hedges and Woodworth (1990) examined many of the inquiry-based science curricula of the 1960's. They compared those curricula with the standard science pedagogy of the day that focused on the facts, laws, theories and applications of science, and the use of laboratory experiences as a supplement to this approach. These investigators found that inquiry-based science instruction was superior in improving students' attitudes about science, general academic achievement, reading and math skills, and process skills of science. More recently, other literature has echoed these findings. Hurd (1998) noted that much understanding of the nature of science may be fostered by inquiry-based instruction. These understandings include the limits of science, how research is done, science as a social endeavor, what counts as scientific evidence, and how to recognize good and bad scientific practices. Inquiry may also facilitate a deeper understanding of concepts, critical thinking, and may even help with the building of scientific vocabulary (NRC, 2000). Another advantage to inquiry is that math skills are frequently practiced in a meaningful context during scientific inquiry as well (AAAS, 1990). Finally, Staver (1998) suggested that socially based inquiry might hold promise for dealing with students' alternative conceptions about science. The key in this case appears to be the extensive social interactive that certain forms of inquiry tend to promote. Alternatively, Enger and Yager (1998) have warned that preconceptions and prior knowledge may actually bias what students pay attention to and conclude during the course of a scientific investigation. Seeking a balance between inquiry and explicit instruction may help to alleviate the concern about students' preconceptions and their learning of important concepts.

Overview of Assessment in Science Education

If students are expected to work like scientists, they must also be evaluated in ways that are consistent with the activities of scientists. Professional scientists are regularly evaluated within their community of practice in formal and informal ways. For example, they may present lectures or workshops in the presence of their peers. They also may write and submit research reports for publication in professional journals. These papers are often peer reviewed and peer edited. Those scientists working in industry may often be required to sell their ideas or products to commercial markets. Professional scientists, in their day-to-day activities, do not usually take traditional paper and pencil tests that measure one's ability to recall bits of isolated factual information. Evaluation, for the professional scientist, is more directly linked to the work they do.

Unfortunately, much of our current classroom assessment methods rely heavily on the paper and pencil sorts of tests that are far removed from real scientific practice. In fact, comparatively little has been explicitly written about assessment of scientific inquiry in the contemporary literature or about alternative science education assessment in general (Slater, Ryan & Samson, 1997; Zachos, et al., 2000). It is easier for most science educators to find research about traditional assessment techniques than about alternative and authentic techniques specifically geared toward assessment of inquiry. Therefore, for the purposes of this review, the author was often forced to consider the potential merits of alternative assessments in the literature that did not specifically deal with inquiry. These assessment methods were considered if they appeared to have obvious potential for the evaluation of inquiry. Finally, a few attempts to assess inquiry in college science classrooms will also be considered in this section.

Enger and Yager (1998) reported to us that there are two types of alternative assessment that must become central to the authentic science classroom. First there is authentic assessment. In this case, assessment occurs within, and is closely related to, the context of the learning. In other words, the assessment authentically matches the learning goal. Another component to authentic assessment, as it is used within this research project, is that it may match the sorts of assessment used in the actual community of practice of professional science. For example, if a teacher wishes to assess students' skills in using a microscope, a paper and pencil test is probably not an authentic test. A better assessment choice may involve asking the students to prepare a slide for viewing and actually bring it into view with a microscope. The student may then be asked to draw or describe the specimen in accurate detail. The assessment is authentic in this case because it has a direct connection to the learning task. It is also something that a professional scientist might actually do. The second important type of alternative assessment is performance assessment. In this case students are asked to perform a task or demonstrate a skill related to their classroom instruction or learning. The above example of demonstrating skill with a microscope is a performance assessment in this sense. Both of these forms of assessment, authentic and performance, must be kept in mind if we are to have valid assessment of students' inquiry work within a collaborative community of learners.

Teachers are being encouraged to use a variety of techniques to monitor their students' progress and to assess throughout the various aspects of science activities, on an ongoing basis. These techniques include not only paper and pencil tests but also tasks, which are authentic, and performance based and which ultimately serve to guide, rather than just quantify, the learning process (Perkins & Blythe, 1994; NSTA, 1996; Ochanji, 2000). Some writers have even suggested that if teachers carefully select good assessment activities, instruction and assessment may overlap so completely that the traditional barriers between the two may disappear. In other words, assessment has the potential to become a routine part of learning rather than just an end-of-activity summative exercise that implies success or failure (Kamen, 1996). Clearly, it is important to keep in mind what the students are doing and to select assessment practices that match their work.

Science students who are engaged in inquiry may be evaluated by any of several means. They may be asked to produce some end product related to their inquiry-based experience. They may be evaluated based on their ability to use laboratory equipment, pose questions, carry out an experiment, work cooperatively with peers and/or work on their own. They may be asked to make displays of their work or contribute artifacts based on their work (NSTA, 1996; Slater, Ryan & Samson, 1997; Zachos, et al., 2000). What follows is a very general list of other ideas for evaluating the work of students who have worked within a social constructivist framework in science class. These evaluation methods may, arguably, be applied to inquiry-based science lessons.

Checklists and scoring rubrics (Doran, Chan & Tamir, 1998; Enger & Yager, 1998) may be used to evaluate students on skills, products or processes related to inquiry. A checklist is a listing of skills, tasks or behaviors students must complete over the course of an activity or over a specified time. As the evaluator finds evidence of a particular item on the list, the item is checked as completed. During inquiry activities, teachers may monitor the work of individual students or of cooperative groups by way of a checklist. Examples of items on a checklist for an inquiry activity could include safety techniques, correct use of measuring devices, stating a hypothesis or a researchable question, observation, reflections about a procedure, or a conclusion (Collins, 1992; Germann & Aram, 1996; Ochanji, 2000). Scoring rubrics or evaluation sheets carry the idea of the basic checklist a step further. Most of them tend to focus on quantification by listing not only expected tasks, behaviors and skills but also by setting standards at which the student is expected to perform (Enger & Yager, 1998). Doran, Boorman, Chan and Jejaly (1993) recommended routine use of a rubric for evaluating skills, tasks and behaviors commonly observed during inquiry-based activities.

Students engaged in inquiry may be evaluated by experts (teachers, professionals, etc.), by peers, and even by self-evaluation. A checklist or rubric may be used to guide the process. Students may be asked to construct a concept map based on their on-going research (Roth, 1995; Ruiz-Primo & Shavelson 1996). Students may also be asked to collect artifacts of their work in a portfolio, which may be evaluated by a rubric or checklist (Slater, Ryan & Samson 1997). Student journals and laboratory notebooks may also serve as a basis for evaluation (Keys, et al., 1999; Shepardson, & Britsch, 2001). Finally, students may be asked to defend their ideas, present seminars, prepare bulletin boards or other displays of their work. The key is that the tasks students are asked to do for a grade should reflect their work. As previously noted, these are typical of the sorts of things that a professional scientist would do within the context of their work. In other words, the assessment tasks are authentic. Also, use of a variety of assessment techniques is generally recommended.

Some college science teachers have reported success with teaching by inquiry in Journal of College Science Teaching. Keefer (1998) outlined criteria for effective inquiry activities in the college classroom but said little concerning assessment. The author has evaluated college biology students by way of a formal research report reflecting their inquiry activity (Lunsford, 2002). Harker (1999) described supplementing the requirement of a research report with requiring students to write a research proposal before beginning their experimentation. Students also presented their results in a seminar-type format to peers and other interested individuals at their school. Henderson and Buising (2001) described a research-based molecular biology course that involved an even greater variety of assessment techniques. In this course, students were required to write mock grant proposals and restrict the cost of their research projects to a specified amount of money. They also posted data and other items on a class web site, kept laboratory notebooks, prepared posters to summarize their work and wrote research papers. Further, the students participated in the regular peer evaluation sessions that had an impact on their course grades.

The Problem of Assessing Inquiry

As noted above, several potential ways exist by which students who are learning science through inquiry may be evaluated. However, these practices are not widespread. Both authentic science and authentic assessment are consistent themes in the science education reform recommendations mentioned above. These themes may be effectively addressed together. Buxton (2001) notes the need to evaluate students based on the work they do during lab activities. Germann & Aram (1996) note that the recording of data is central to understanding the process of scientific inquiry.

With so many diverse ideas about what constitutes inquiry and with such a heavy emphasis on inquiry, it is clearly necessary to have a valid, sound method of evaluating the work of students who are engaged in the process (Zachos, et al., 2000). A few researchers have noted that student writing in science class has recently been considered in terms of its usefulness for assessment (Audet, Hickman & Dobrynina, 1996; Keys, Hand, Prain & Collins, 1999). There is ample evidence to suggest that the scientific inscriptions made by students as they construct science might hold a powerful key to the assessment of scientific inquiry. If students are indeed expected to think and act like scientists, and if scientists are makers and users of inscriptions, then it follows that student-made inscriptions represent a unique opportunity for the authentic and performance based assessment of students as they engage in scientific activity.

Overview of Scientific Inscriptions

The word inscription, according to most dictionaries, is derived from the Latin words "in" and "scribere." In the most general sense of the word, then, an inscription is something "written in" or "written down." In the field of professional science, the term inscription first gained attention following an ethnographic study of a group of professional scientists and technicians (Latour & Woolgar, 1979). These researchers noticed two striking things in their study. First, they provided compelling evidence that scientists are highly "social" in their practices and that they negotiate and build scientific knowledge within their social communities of practice. Second, Latour and Woolgar remarked that the scientists in their study had a "strange mania for inscription" (p. 48). The following excerpts from Latour & Woolgar (1979) speak volumes about this mania for writing.

> It seems that whenever technicians are not actually handling complicated pieces of apparatus, they are filling in blank sheets with long lists of figures; when they are not writing on pieces of paper, they spend considerable time writing numbers of the sides of hundreds of tubes (p. 48).
>
> The samples extracted from rats are put into one of the pieces of apparatus and undergo a radical transformation: the machine produces a sheet of figures. One of the participants tears the sheet from the machine's counter and, after scrutinizing it carefully, arranges for the disposal of the tubes...The focus of attention shifted to a sheet of figures. After a short time, the computer printed out a data sheet and it was this, rather than the original sheet of figures, which was regarded as the important end product of the operation...[it] was merely filed alongside thousands like it. (p. 49-50).
>
> Xeroxed copies of articles with words underlined and exclamation marks in the margins are everywhere. Drafts of articles in preparation intermingle with diagrams scribbled on scraps of paper...excerpts of draft paragraphs

> change hands between colleagues while more advanced drafts pass from office to office being altered constantly, retyped, recorrected and eventually crushed into the format of this journal or that. When not writing [they] scribble on blackboards, or dictate letters or prepare slides for their next talk (p. 49).
>
> Once the end product, an inscription, is available, all the intermediary steps which made its production possible are forgotten. The diagram or sheet of figures becomes the focus of discussion. (p. 63).

Latour and Woolgar (1979) further reported that the inscriptions scientists produce become a sort of mediating device in their social interactions. The inscriptions become the focus of "science talk" among the members of the community of practice. For example, the following quotations are from scientists (in Latour and Woolgar's study) observing a graphical inscription: "How striking." "A well differentiated peak" (p. 50). It seems clear from Latour and Woolgar's chronicle that inscriptions guide practically every conceivable step of the scientific process from initial experimental design to writing and evaluating professional scientific papers. In more recent publications, Latour (1987) and Kozma, et al. (2000) noted that a well prepared inscription helps a scientist to argue the efficacy of their results and scientific claims and that inscriptions facilitate group interaction and interpretation. They are commonly used in scientific symposia and in professional journals to initiate and mediate discussion or discourse concerning a scientific concept (Lynch & Woolgar, 1990; Meira, 1995; Kozma, et al., 2000).

Inscriptions have more recently been considered in terms of their usefulness in recreating the authentic science of inquiry-based learning, described above. The work of Latour and Woolgar (1979), Latour (1987) and

Lynch and Woolgar (1990) clearly illustrated that inscriptions were a powerful means of communication in professional science and that they were a means by which an individual's mental representations may be moved into a social arena. Henderson (1991) noted that inscriptions are so central to science that it is not out of the ordinary for a meeting among scientists or engineers to grind to an abrupt halt as an inscription is prepared or retrieved from another location. With these facts in mind, and with the idea that inscriptions are intended to represent nature in an abstract way, Roth and McGinn (1998) proposed that inscriptions may hold valuable promise in science education. These authors stress that student and/or teacher made inscriptions should be authentic and derived from authentic scientific practices (inquiry). In the classroom, inscriptions may take many forms. These include lists, labels, photographs, computer files, maps, grids, drawings, diagrams, concept maps and other examples of representations produced during scientific activity or science talk (Roth & McGinn, 1998). To further characterize inscriptions in professional science and in the science classroom, it is of note that their central function is to communicate information to others (Latour & Woolgar, 1979; Lynch & Woolgar, 1990).

When an inscription becomes such a central focus of conversation that it is actually guiding the conversation and being "built" as the conversation progresses, it is known as a "conscription" or "conscription device" (Roth & McGinn, 1998). Also of note is the fact that inscriptions are permanent, mobile, and can be combined with other inscriptions to form more abstract representations of scientific data. This process is known as transformation and may reflect a cascade effect as several basic inscriptions are superimposed to form the more abstract inscription (Roth, 1995; Roth, et al., 1998). For example, a set of observations notes, questions, and data from tables and may be transformed into a graph. A series of observations and remaining questions may be organized into a concept map. Further, inscriptions are subject to easy reproduction and are readily changed in size. Also they are publicly accessible and shift a person's individualized representations to that of the social group. Inscriptions that are used across various fields of practice and across space and time are sometimes known as "boundary objects" (Roth & McGinn, 1998). Foster (1998) noted that student-made inscriptions are useful in helping students to think about and remember their observations. Also, they provide a teacher with powerful insight on a student's reasoning at a given moment and over extended periods of time. A key aspect of good science instruction is the ongoing assessment of students that would occur at the beginning, end, and throughout the duration of an activity (Perkins & Blythe, 1994; Enger & Yager, 1998). Scientific inscriptions are capable of providing much assessment information of this type.

Why Inquiry and Inscriptions In Science Class?

In this section, it will be argued that scientific inquiry represents a sound pedagogical practice and that inscriptions represent a valid assessment tool. Scientific inquiry stimulates many senses and may be performed at various levels of complexity by individuals or by groups. It is rooted in the social constructivist philosophy of learning. It is a generally accepted notion that most students learn best by progressing from concrete experiences to more abstract ones (AAAS, 1990). This progression is typical of scientific inquiry. Further, there are calls for various types of on-going assessment in the science classroom in lieu of traditional paper and pencil tests that emphasize factual recall (Perkins & Blythe, 1994; NRC 1996). These more traditional tests are inconsistent and invalid when compared to the goals of encouraging understanding and critical thinking about science (Bol & Strange, 1996). As previously discussed, scientific inscriptions allow students and teachers to share in and negotiate the construction of knowledge. Crawford, Kelly and Brown (2000) stated that opportunities which allow such engagement help students to move beyond narrow content knowledge and allow them to see the social aspect of scientific knowledge construction as they begin to talk about, write out and negotiate meaning within their learning community. This is consistent with the notions of written and oral discourse in science classrooms which has been described by Klaasen and Lijnse, (1996) and by Kelly and Green (1997). More recently, Kelly and Chen (1999) noted that opportunities to engage in written and oral discussion of science allows teachers to better gauge students' understandings of how students utilize scientific evidence to make scientific claims. Inscriptions are a written record of thinking and/or observations. They allow one's individual mental representations to be moved into a group context. Some inscriptions, as previously noted, are socially constructed. Also of note about inscriptions is the fact that these written documents progress from simple to abstract and represent documentation of "in the moment" thinking as well as progression in thinking over extended periods of time.

A recent study of twelve preservice science teachers involved an examination of how these students produced and used scientific inscriptions while involved in an environmental science study. The researchers concluded that the students produced quality inscriptions and that those inscriptions fostered in-depth discussion among the research participants. However, an additional conclusion of the study was that the students did not fully understand or appreciate the complexity of the data represented in the inscriptions which they generated (Barnett, MaKinster, Barab, Squire & Kelley, 2001).

Concluding Remarks

This review of the literature has provided detail on social constructivism as a research paradigm and educational philosophy. Evidence has been presented that scientists socially construct much of their knowledge within collaborative groups. The implications of these features of science on science education have also been detailed in terms of reform recommendations for the teaching of science. The concept of scientific inquiry as a pedagogical practice has been discussed, along with the need for valid and authentic means by which to assess students who learn by this method. Scientific inscriptions have been defined and suggested as a possible important key to the assessment of inquiry. In the next chapter, Chapter Three, the methodology of the study and the paradigm from which the researcher operates will be detailed.

Chapter Three: Methods

In the previous chapter, Chapter Two, a review of the literature focusing on science education reform recommendations, scientific inquiry, scientific inscriptions and social constructivism was presented. This chapter, Chapter Three, will detail the methodology of this study. A description of the research participant population, methods of data collection and data treatment procedures will be detailed. Related information, pertinent to the data collection and analysis process, will also be included.

Research Participants

The participants in this research study were a group of preservice science teachers who were all enrolled in a graduate program in science education at a major Southeastern state university. This university has adopted various recommendations and positions pertaining to teacher education that are advocated by the Holmes Group (Holmes Group, 1995). This group promotes reform and celebrates excellence in several aspects of teacher education. One of the central platforms of the Holmes Group relates to the academic preparation of perspective teachers. They denounce the tendency of some colleges and universities to provide potential teachers with diluted academic experiences in the content areas. The Holmes Group argues that prospective teachers should receive content instruction that is at least equal to that received by pure content majors in the liberal arts and sciences (Holmes Group, 1995). The university, therefore, requires that potential teachers hold or complete a Bachelor's degree in the content area before beginning a teaching internship.

The participants involved in this study (n=10) were all seeking certification to teach biology at the secondary (high school) level. The student's ages ranged from 21 to 43 years. The mean age was 28.3 years, the median age 25.5 years. Five of the students were male and five were female. The secondary education program these students were enrolled in is a fifth year program based on Holmes Group goals and recommendations.

During this research study, the ten participants were enrolled a course entitled "Knowing and Teaching Science: Just Do It." They came to the course with what could arguably be described as extensive academic backgrounds in science content. They had all met or exceed the minimum number of hours in biology required to be licensed to teach. Seven of the students had bachelor's degrees in biology or in an academic discipline related to biology. One had a bachelor's degree in business and two were upper level undergraduates. All of the students' academic transcripts were laden with undergraduate courses such as general biology, chemistry, zoology, exercise physiology, physics, ecology, geology, and microbiology.

A few of the students had some work experience relating to the biological sciences. Two had worked in pharmaceutical sales, another in medicine. Every participant in the study identified strongly with the sciences, particularly biology, in their academic histories and/or their life experiences. Despite the heavy academic emphasis on science content, the students lacked quality, first-hand experiences with actual scientific research. None of the students' academic transcripts revealed such research-based experiences. The students were also asked by their academic advisor (who helped to design and who helps to teach the "Just Do It" course) about past research experiences. All students were found lacking in this area. Only one student, Alice[1], even came close. She had worked in a veterinary office and animal hospital. As a student, she had been marginally involved as an assistant in a group-based zoological field research project. Alice's advisor, Dr. Taylor, encouraged Alice and the other students to enroll in the "Just Do It" course in order to experience detailed, long-term scientific investigation on a first-hand basis. Table 1 presents a summary of each participant's educational background and the science-related work experiences, if any, they had.

Research Setting

This study was completed over the duration of the participants' enrollment in the "Knowing and Teaching Science: Just Do It" course,

Table 1: Description of Participants

PSEUDONYM	AGE	DESCRIPTION
Alice	25	Bachelor's degree in zoology. Previously worked in veterinarian office and in an animal hospital. Helped complete some group zoological research as a student.
Basma	24	Bachelor's degree in biology. No previous work experience related to science.
Greg	26	Bachelor's degree in biology. Previously worked as a veterinarian technician and spent 2 years in army.
Morgan	21	Bachelor's degree in biology. No previous work experience related to science.
Phillip	22	Upper division undergraduate. No previous work experience related to science.
Ralph	43	Bachelor's degree in biology. Previously worked for 15 years at various jobs including working as an unlicensed physician assistant.
Richard	31	Bachelor's degree in business administration. Previously worked for 5 years in pharmaceutical sales.
Sara	26	Bachelor's degree in animal science. No previous work experience related to science.
Susan	42	Bachelor's degree in biology. Previously worked for 10 years in pharmaceutical sales.
Veronica	23	Upper division undergraduate. No previous work experience related to science.

[1] With the exception of the author's name, all participant names used are pseudonyms.

mentioned above. According to Melear, et al. (2000) this course was specifically designed to address a major science education reform recommendation that calls for teachers of science to utilize the pedagogical practice and science content of scientific inquiry in their science classes. The goal was for the university to produce potential teachers of science who were competent in scientific inquiry. This recommendation is advocated by several national groups (NRC, 1996; NSTA, 1996; NRC, 2000) and required by state policy (Tennessee State Department of Education, 1995). The course, which had been taught four times before this study began, rests on the premise that potential teachers of science will come to understand scientific inquiry if they are actively immersed in such a process. Put briefly, the main goal of the course is to teach preservice science teachers how to do scientific experiments and to give them a model for, and practice in, teaching by scientific inquiry. A specific member of the university's Botany department (Dr. Temple) has always taught the course. A specific member of the science education department (Dr. Taylor) worked with him to develop the course and has traditionally been involved in teaching some aspects of the course. On some occasions she has personally taught portions of the course. At other times her graduate students have cooperated with her to teach some parts of the class. The "Just Do It" course represents a partnership between the university's science faculty and its science education faculty (Melear, et al., 2000).

The participants in this research project worked in a science laboratory classroom in the university's Botany department. These students were the sole occupants of this laboratory during the academic term. No other course met there. The classroom included two rows of laboratory workbenches with chairs, a series of tables for storage/workspace, work sinks and an instructor's workbench. A chalkboard hung on one wall, a dry erase board was positioned on the other. Along the third wall were botanical photographs and a bulletin board. A full row of windows, with blinds, occupied the fourth wall. Further, dissection microscopes and compound microscopes were at the students' disposal. A floor plan of the laboratory is shown in Figure 1. Other equipment and supplies, such as microscope slides and cover slips, dropping pipettes, gas burners, Petri dishes, thermometers, beakers and potting soil, various containers, plant growth lights and incubation chambers were available to the students as well. Other items were either brought to the lab as needed, or the students went to other locations within the building to use necessary equipment and supplies. Early in the course, all students were issued keys to the laboratory classroom. Therefore, the students had access to the lab and their experiments at any time including weekends.

More About the Course

State licensure requirements dictate that all students who are enrolled in the university's secondary science education program must demonstrate adequacy in scientific inquiry before they are granted initial certification to teach within the state. The "Knowing and Teaching Science: Just Do It" course represents only one way by which this achievement may be demonstrated. Other options available to students for satisfying this requirement include first hand research experiences they have had in the past, and the opportunity to work as a laboratory assistant and apprentice with a professional research

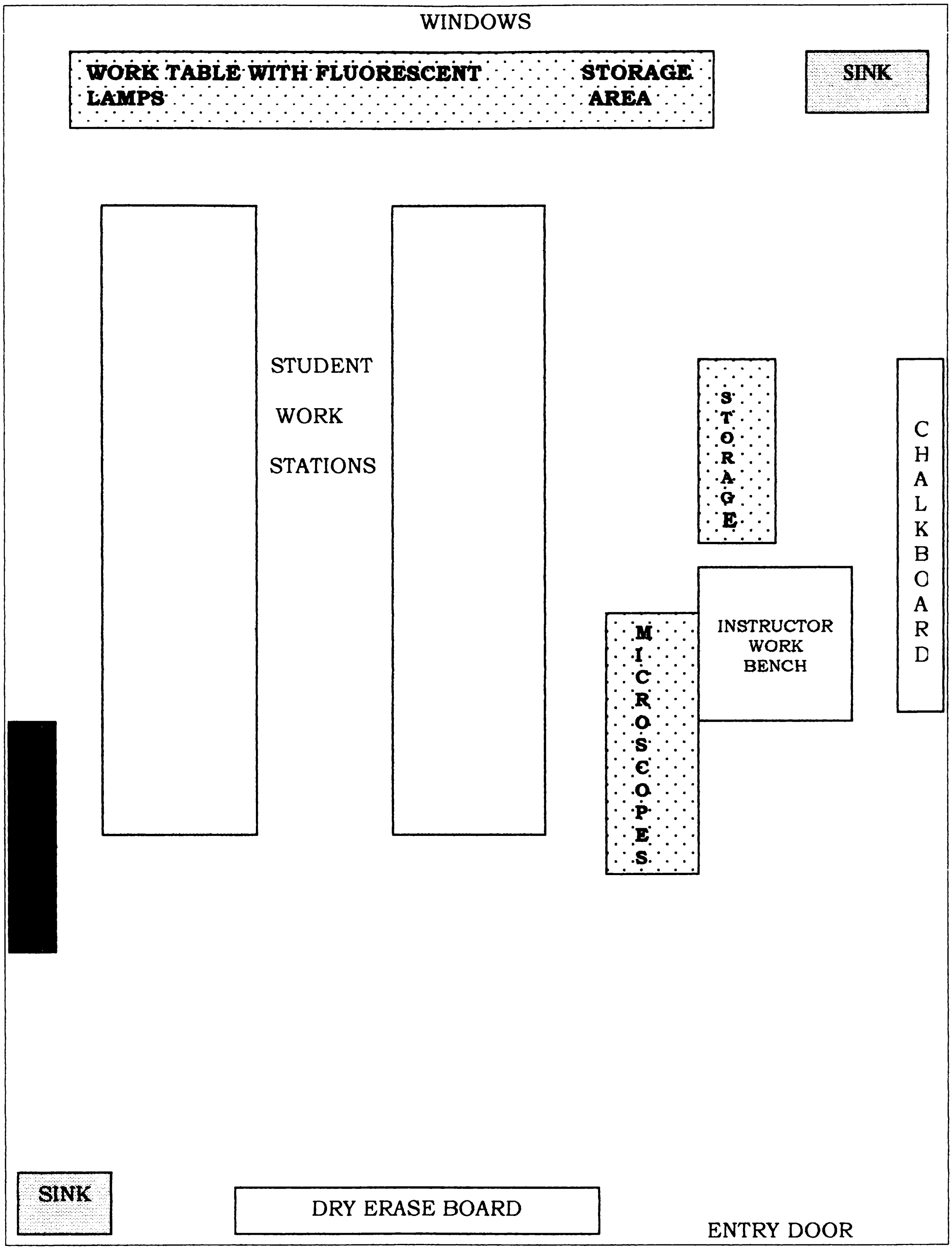


Figure 1: Floor Plan of the Laboratory

scientist. The ten students participating in this study (enrolled in the "Knowing and Teaching Science: Just Do It" course) were all identified as needing some sort of scientific research experience by the science education program coordinator. They were prompted to fulfill this requirement by enrollment in the course. Enrollment in the course was not required but represented one way for the students to fulfill the research competency requirement. The course was promoted by the students' academic advisors, by being listed in the university's schedule of classes and by way of a flier or handbill similar to the one appearing in Figure 2. The course syllabus (Figure 3) is presented in the appendix of this research report.

Knowing and Teaching Science:
Just Do It!
Botany 531, sect 22832
4 credits - Spring 2002
Mon/Wed 12:40 – 3:25 WBA 117

Science is much more than a collection of facts. It is the active study of phenomena through the processes of observation and experimentation. Because of the enormous subject content in the biological sciences, most undergraduate courses provide limited opportunity for students to directly and intensely participate in the actual processes of science. This course is designed to be something different! You will spend an entire semester with a small group of students jointly and independently conducting investigations with an unknown organism. No lectures, no structured labs, no pre-determined results......just doing science with the goal of finding out as much as possible about the unknown and, in the process, gaining a deeper understanding of the true nature of science by constructing your own knowledge.

The course is open to all students, Junior-level and above, with at least 8 hours in any college-level biological science and permission of the instructors. Enrollment is limited. In case of over-enrollment, preference will be given to those planning to enter the teaching profession. This course is appropriate for all elementary and middle (Preteaching Science and Mathematics Teachers) and secondary teachers. Completion of this course satisfies the 7-12 Science Teaching requirement of long-term open-ended experimentation in the major for teacher certification in the State of ___.

For more information contact Dr. ___ (___) or Dr. ___ (___).

Figure 2: Flier Used to Promote "Just Do It"

During this research study, the Just Do It course was essentially team-taught by the two university professors and by two teacher assistants. The teacher assistants were doctoral students in the university's science education department. The course met twice each week for approximately three hours per meeting. The course spanned approximately one semester, sixteen weeks, in duration. At least one of the teacher assistants was present at each meeting. Further, slightly more than about the first half of the course was taught by the Botany/Genetics professor, Dr. Temple, while about the second half of the course was taught by the science education professor, Dr. Taylor. During the entire course, the students were mostly involved in scientific research and inquiry. They also prepared inquiry lessons that were suitable for secondary science education students and engaged in other related activities. More details on the course are provided in Chapter Four.

General Procedures

Because the "Just Do It" course is so unique to science teacher education, it is often the topic of study and observation by science educators at the university (Brown, 2002; Lashley, 2002). A research report detailing the course has recently been published (Melear, et al., 2000_ and at least one other regional university has modeled a similar course for their science education students after the "Just Do It" course (Wilson & Lucy, 2002). Therefore students entering the course were aware, with their informed consent (see Figure 4), that their work in the course would be the subject of research. As part of their course grade, students were required to participate in

You are invited to participate in a research study. The purpose of this study is to assess the effects of a course specifically designed to teach inquiry-based science to a group of preservice science teachers. This project originated as a pilot study of the Salish II research consortium designed to research and implement programs that adequately prepare science teachers for the new standards of teaching, which require student-centered inquiry as the basis of instruction. The Salish II consortium currently consists of university/college faculty in the sciences, science education and cognitive sciences from over 46 institutions in 24 states. The Consortium focuses on the preparation of science teachers as defined by the emerging U.S. National Education Standards and Assessment.

Your participation in this study may include the following:

1. Answering a set of questions on experimental design at the beginning and end of this semester.
2. Answering a set of open-ended questions concerning the Nature of Science at the beginning and end of this semester. This written test will take approximately 30 minutes each time.
3. Completing the Salish Inventory for Demographic Evaluation of Schools and Teacher Education Programs (SIDESTEP). This written survey will take approximately 15 minutes and will be conducted mid-semester.
4. Being videotaped for a pre- and post- course interview. This assessment is an oral interview lasting approximately 10 minutes. The interview will be recorded on videotape and then transcribed. The recording will be stored in a locked storeroom in ____ for five years. The interviews will occur in ____.
5. Submitting a copy of your transcript for analysis of type and number of science credits completed before this class.
6. Providing the last four digits of your social security number for use in coding the data.

All of the above events will take place in room ____ [Building] ____

Risk of Participation

If you decide to take part in this study, the risk of being identified on videotape is possible. Segments of the videotaping will be used in formal scientific presentations like the National Science Teachers Association (NSTA), National Association for Research in Science Teaching (NARST) and other science education conferences. The use of these segments will be to illustrate the innovative approach to teaching inquiry science within this course. Every possible effort will be taken to minimize recognition of the participants. This includes the use of pseudonyms both in the transcription of the audio and videotapes and when referring audibly to the participants during videotaping.

Benefits

The benefits are the likelihood that this project will provide the knowledge and the experience necessary to teach science by inquiry, in ways previously not attained in any other science teacher preparation program. National Science Education Standards recommend that science teachers use the inquiry student-centered strategy (rather than didactic strategies) to teach in the middle to high school. The pilot project will provide a built in science research experience to teach science by student-centered inquiry.

Confidentiality

The information in the study records will remain confidential. All data will be stored securely and will only be made available to persons conducting the study unless you specifically give permission in writing to do otherwise. No direct reference will be made in oral or written reports which could link you to the study.

Contact

If you have questions at any time about the study or the procedures, you may contact the researcher, Dr. ___ at ____, phone number ____. If you have questions about your rights as a participant, you may contact the Compliance Section of the Office of Research at ____.

Participation

Your participation in this study is voluntary; you may decline to participate without penalty. If you decide to participate, you may withdraw from the study at anytime without penalty and without loss of benefits to which you are otherwise entitled. If you withdraw from the study before data collection is completed, your data will be returned to you or destroyed upon your request.

I have read and understand the above information. I have received a copy of this form. I agree to participate in this study.

Participant's Signature ________________________ Date __________
Investigator's Signature ________________________ Date __________
B. Ed Lunsford/____
Last 4 digits of your social security number ____________

Figure 4: Informed Consent Form

various activities that form not only the basis of the class, but the basis of this research project as well. The author (Eddie) acted as a participant-observer during the course. His role was multiple. In addition to collecting data for this research project, he was also a paid teacher assistant. His duties included monitoring and assisting students with their inquiry projects, under the supervision of the two course instructors; helping students to procure necessary supplies and equipment, providing feedback to students; and grading students on their individual laboratory inscription notebooks. The other teacher assistant (Denise) had similar duties. She also assisted with the students' work and communicated with them regularly by way of reading their entries and writing her own comments in reflective journals each student maintained. More details on the reflective journals are offered (see subsection entitled "Student Reflective Journals") in this chapter.

Philosophy and Description of Data Collection Methods

Since qualitative research philosophy and methods generally place high value on the experiences of people, they are ideal for making sense of research occurring in a social context. Peshkin (2000) noted that any research methodology influences the way in which people are regarded and treated during a study. Qualitative research methods are highly consistent with the co-construction of knowledge or reality that characterizes the social constructivist approach. Research participants are valued for their insight, not just their participation. To that end, two research methods were utilized in this study because of their focus on the experiences of research participants. These two methods are the in-depth interview and participant observation.

The In-depth Interview

Extended individual interviews with each participant in a research study represent a common method of data collection in many fields, including science education. Participants may include students, teachers or other knowledgeable and/or interested persons. McCracken (1988) described a protocol for the "Long Interview." A sample size of eight or fewer participants is regarded as ideal. A variation of the Long Interview may be used to interview multiple participants during a single session. This variation is known as the Focus Group (Morgan, 1998). In both of these interview processes, a discussion guide is often used to focus and guide the conversation. This guide provides basic questions and prompts that relate to the research questions at hand. It may be prepared following a review of the literature concerning what is known about the question of interest. Some researchers refrain from completing an in-depth literature review prior to construction of the discussion guide. It is important to note that use of the discussion guide is not intended to prohibit interviewees from talking about other issues they wish to discuss during the interview. Informed consent should be sought from each research participant before the interview actually begins (Patton, 1982; McCracken, 1988).

Both Patton (1982) and McCracken (1988) further recommended that the entire interview should be recorded on audio/and or videotape. Verbatim transcripts of each interview should be made from these recordings. During the analysis, the researcher may consider the interviewees' comments, the literature review and his or her own personal experience in an effort to draw conclusions or consider suggestions for additional interview time. Consistent themes among the responses should be noted. Themes that appear over and over, to the point of redundancy, are particularly critical. Finally, the entire study should be considered in terms whether interview participants bring out such themes. These factors should be used to evaluate the overall efficacy and quality of the study and its results (McCracken, 1988). The in-depth or long interview may stand alone as a valuable research methodology. Also, it may be part of a second method, participant observation, which is described below.

Participant Observation

Participant observation is a highly adaptable qualitative research methodology. It fits well within the social constructivist framework in that the researcher seeks to, as the name implies, actively construct meaning while situating himself within the group of those participating in the phenomenon being studied. The researcher attempts to share the group perspective (Denzin, 1988). He/She often enters the situation with an unusually open-ended personal perspective. A very basic initial research question may be repeatedly revised as the long-term study progresses. The researcher may marginally or wholly participate within the group. Further, the researcher may be positioned at most any social or functional level within the group during the study (Jorgensen, 1989).

During the research process, any number of methodological data gathering techniques may be utilized. These methods include interviews of participants and/or informants, collection of census data, and analysis of historical documents and artifacts from the group (Denzin, 1988). Informal conversations, personal reflections, video and/or audio recordings, artifacts, reflective observations, research notes and any number of other data sources may be used alone or in combination to draw conclusions. The long or in-depth interview (see above) may provide a wealth of data. The most central aspect is that, generally speaking, the researcher (and perhaps the participants) utilizes inductive logic throughout the study (Jorgensen, 1989). The phenomenon is initially examined with or without a hypothesis in mind. As necessary, the developing hypothesis and/or the basic research question may be modified in light of research findings. In short, patterns and findings most often emerge from the data, rather than being imposed upon them by predetermined theory. This process is known as analytic induction or inductive analysis (Denzin, 1988; Patton, 1990). Since participant observation is strongly appropriate for studying human interactions, poorly understood phenomena, differences in perception between outsiders and insiders, and readily observed happenings (Jorgensen, 1989) it appears that this method is highly appropriate for the research questions (see Chapter One) of this study.

Issues of Validity and Reliability

The usefulness of data from qualitative studies is often the subject of intense debate. McCracken (1988) suggested that this issue might be due to the tendency of some people to judge qualitative data in terms of traditional quantitative standards. Some people avoid this dilemma altogether by claiming that the purpose of their qualitative study is purely descriptive for a specific situation. In any event, the issues of validity and reliability are important to this research project. These issues will be considered below in separate subsections.

Validity

Validity is most simply addressed by the following question: "Does the research measure, describe or document what it is intended to measure, describe or document?" In very general terms one may argue that most qualitative research studies are highly valid. This is due to the fact that most of them emphasize the words and actions of the research participants (Singletary, 1993). Participant observation, in particular, stresses the role of the meaning that research participants assign to their language and activities (Jorgensen, 1989).

A few more specific types of validity are recognized. Construct validity involves clearly identified and defined operational definitions for the concept in question. Internal validity involves the attempt to establish cause and effect relationships. If this is part of the research goal or conclusions, one's observations must reflect genuine features and relationships found in the study. External validity involves the question of whether one's research conclusions or findings may be generalized to other populations. If this is claimed, one must argue that the research participants are representative of other populations (Fortner & Christians, 1989; Yin, 1994). To increase the validity of a qualitative research study, a few basic recommendations should be kept in mind. Jorgensen (1989) recommended that the researcher take full advantage of their access to the world of the research participants. Also, he suggested testing tentative concepts by discussing them with participants and considering whether the concepts are observable in the real contexts of the research situation. He also recommended use of multiple procedures and data sources. This use of multiple sources and procedures is also known as triangulation. Triangulation increases the validity of a study. Methods triangulation is use of multiple research methods. Analyst triangulation is use of multiple researchers or analysts in evaluating data. Theory/perspective triangulation involves considering the data in terms of more than one theoretical perspective (Patton, 1990).

Reliability

In general terms, reliability refers to the question of whether one's study (including the data collection and results) may be repeated with identical to very similar results (Yin, 1994). Both Jorgensen (1989) and Singletary (1993) suggested that one should expect a decrease in reliability with most qualitative research studies when they are compared to quantitative methods and studies. Singletary (1993) noted that this decrease is probably due to the heavy emphasis on validity and "real worldliness" of qualitative research. Bogdan and Bilken (1997) admitted that two researchers, who would have different experiences, backgrounds, perspectives and questions, might very well arrive at two different types of findings while researching the same population or basic question. In conclusion, it appears that reliability may be more problematic for the qualitative researcher than validity. Specific comments on the validity and reliability of this study are discussed in Chapter Five.

Data Sources

As previously noted, the research methodology of participant observation traditionally makes use of a wide variety of data sources and data collection techniques (Denzin, 1988). The use of multiple data sources (triangulation) represents one way by which the validity of a qualitative research project and the sureness of its conclusions may be increased. To that end, data from this research project comes from seven primary sources. These are (1) Long Interviews. (2) Videotapes of Class Meetings. (3) Student Reflective Journals. (4) Student Laboratory Inscription Notebooks. (5) Authors Notes and Reflective Journal Entries. (6) Focus Group with Members of a Previous Cohort and (7) Miscellaneous Artifacts. Each of these sources is described below.

Long Interviews

An individual pre-class interview was held with each participant on the first day of class. The interviews were conducted by the author (who was a teacher assistant for the course and a participant-observer in class) and spanned approximately ten to twenty minutes each. A discussion guide (Figure 5) was used to facilitate the interviews. A post-class interview was held with each participant on the final day of class. This interview was also conducted by

You are invited to participate in an interview as part of our research study which was described to you on the "Informed Consent Form." This interview will be videotaped. I will ask you the following five questions and possibly some follow up questions. **There are no correct answers**. I am interested in your opinion. Your answers will not affect your course grade. You may wish to read over the questions prior to our interview.

1) What is science?

2) What is the scientific method?

3) I am going to show you some seeds from a popular decorative plant. How would you design an experiment to determine whether natural light or artificial light would cause a better growth rate of these plants?

4) What way(s) could you represent your experiment and your results on paper?

5) How could you, as a scientist, use the representations you described in question number 4?

Figure 5: Discussion Guide For Pre-Class Interview

the author. The individual interviews spanned approximately fifteen to twenty minutes each. A discussion guide (Figure 6) was used to facilitate and pattern these interviews as well. In both the pre-class and post-class sessions, the interviews were recorded on videotape. Further, verbatim transcripts of the interviews were generated. Finally a third interview, the concluding interview, was held with six of the ten primary participants. The remaining participants were unavailable for interview due to personal scheduling conflicts. The purpose of the concluding interview was to collect some additional basic census data from the research participants, to recap the participants' thoughts on their class experience and to consider, verify and discuss emerging themes and research findings with them. These interviews spanned approximately five to fifteen minutes each. In all cases the interviews were recorded on audio and/or videotape. Also, participants were given copies of the interview questions a few minutes prior to all interview sessions. Transcripts were made of these

1) Look at your answers from the last interview concerning the questions "What is Science" and "What is the Scientific Method?" Do you have anything that you would like to add to your previous responses?

2) Imagine that you have just been introduced to a new student at [this university]. This student says, "I've just found out that I will have to take a course called *Knowing & Teaching Science: Just Do It*. What is this course like?"

3) Look at the method by which your grade will be determined in this course. What comments do you have regarding how you have been (or will be) evaluated?

Further prompts to use as necessary:

Ask about usefulness/evaluation of laboratory notebook.

Ask if they have any suggestions, comments or ideas regarding this study.

Ask if they have anything else they wish to discuss.

Figure 6: Discussion Guide For Post-Class Interview

interviews as well. It is also of note that a discussion guide (Figure 7) and a request for an academic transcript (Figure 8) helped to focus and guide the concluding interviews.

Videotapes of Class Meetings

Approximately fifteen hours of the class were videotaped. The individual videotaped sequences include formal student presentations, class discussions, informal observations of, and interviews with, students at work; as well as instances in which the video camera was positioned to record a wide-angle view of the class. During these wide-angle video tapings, no specific or particular event or student was purposefully recorded. Rather, the goal was to record the entire group of students who were in the room at that time. Verbatim transcripts of selected segments of videotapes from the class were made. The segments chosen for transcription appeared to the author to be most directly related to one of the four primary research questions of this study.

Student Reflective Journals

Students were required to keep a written reflective journal as part of their course grade. They made periodic entries in these journals about the experiences, concerns, frustrations and successes they experienced in the course. The students were required to maintain computerized copies of these journals and to submit them to Denise, a teacher assistant for the course. This teacher assistant made regular comments and suggestions in the journals and returned them to the students regularly. Files containing copies of the journals were provided to the author.

Note: Inform each interviewee that the purpose of this Concluding Interview is to (1) gather census data about the class (2) to allow them to recap their course experiences and (3) to ask any necessary follow-up questions.

1. Tell me about your past educational experiences before enrolling in the "Just Do It" course last Spring semester.
   Prompts as necessary:
   - Current degree program
   - Current career goals
   - Previous degrees
   - Previous work experience
2. What educational experiences have you had since completing the "Just Do It" course last Spring semester?
3. Go to personal Emerging Themes # 1 notes
4. Go to personal Emerging Themes # 2 notes
5. Tell me the one thing that stands out about your "Just Do It" experience.
6. Tell me about any experiences you have had with inquiry & inscription since "Just Do It."
7. I would like to ask some of you to read drafts of some of my research before it is finished in order to check my findings against your experiences. Would you be interested in doing so?

If so, please leave your name and mailing address below.

____
____
____
____

Figure 7: Discussion Guide for Concluding Interview

Dear Students,

On November 26 I will be visiting your class and conducting a brief concluding interview with those of you regarding your experiences last year in the "Knowing and Teaching Science: Just Do It" class.

During this interview, I will be asking your recent thoughts about the experience you had in the class, some questions about your past academic history, and possibly one or two other follow up questions. I (not you!) will be transcribing these interviews.

On November 26, please bring a copy of your up-to-date college transcript(s) to this interview for me. I will examine your transcripts to document previous science courses you have had as well as past and current degree programs you have been enrolled in. I am not particularly interested in your grades in these courses. In fact, if you would prefer to do so, you may remove your name or your grades from the transcript copy that you provide to me. I do not require an official copy of your transcript. In fact, a legible photocopy, current through Fall, 2001, will suffice. If for some reason you are not able to get the transcript by this date, your teacher will accept it for me the following week, December 3.

I look forward to seeing you again on November 26. Remember to bring a copy of your transcript if you do not mind doing so. I appreciate all of your past help with my research. If you have any questions for me prior to the interview, please feel free to send an e-mail to me at the following address: eddielun@_______. Thank you again, in advance, for your continued help.

Sincerely,

Eddie Lunsford, Ed. D. Candidate in Science Education

Figure 8: Request For Academic Transcript

Student Laboratory Inscription Notebooks

Students were required to keep a notebook of the inscriptions they made while engaged in inquiry and other course activities. The journals were constructed in a way that allowed students to make carbon copies of all entries in the laboratory inscription notebook. The author periodically examined the notebooks, frequently providing suggestions and feedback to the students. Finally, the notebooks were graded according to a rubric (Figure 9), which had been provided to students at the beginning of the course. The rubric was fashioned with the uses of inscriptions by professional scientists in mind and included criteria such as improvement in inscriptions over time, social use of inscriptions and transformation of inscriptions from simple to abstract. The author received carbon copies of each student's laboratory inscription notebook.

Author's Notes and Reflective Journal Entries

The author made personal notes and reflections in a private journal that he kept throughout the duration of the course. The notes included physical descriptions, statistics and comments about the class format. The personal reflections dealt with unfolding hypotheses and emergent design analysis for this study.

Focus Group With Members of a Previous Cohort

A brief group interview (focus group) was held by the author with three members of a previous cohort of "Just Do It" students. This cohort completed the course during the Fall, 2000 term at the university. These students were required to keep a laboratory notebook during the course but were not given

LABORATORY-INSCRIPTION NOTEBOOK

Your laboratory-inscription notebook will account for ten percent of your total course grade. Listed below are the criteria upon which your notebook will be evaluated. Your completed notebook will be due _________. At this time, please hand in all carbon copies to me, along with this sheet. I would like to look over your notebook periodically, at least two or three times, throughout the course as well. I encourage you to frequently exchange and share your carbon copies within and among your lab groups too. Be sure to get all of your own carbon copies back, and organized into a completed notebook, before the due date. Please feel free to ask me any questions concerning this assignment that you have. You may ask me in person or by e-mail, eddielun@_______.

Criteria	Absent	Poor	Fair	Adequate	Good	Excellent
***Total number of inscriptions** (50 = adequate)	0	2	4	6	8	10
*** Neatness & Clarity** (labeling of figures, listing names of partners, dates, references to other pages, units of measurement, etc.)	0	2	4	6	8	10
*** Transformation Cascades** Combining simpler and less abstract inscriptions (lists, Vee diagrams, sentences, drawings, photographs, maps, tables, etc). into more complex and abstract ones (concept maps, graphs, composite drawings, equations, etc.). (8 = adequate)	0	6	12	18	24	30
***Social Use of Inscriptions** Share ideas, data, methods, etc. Document meetings within & between groups. Use others' ideas in your own inscriptions. (8 = adequate)	0	6	12	18	24	30
*** General improvement over time** (choice of material for inscriptions, better quality, increasing incidence of social use and transformation of inscriptions etc.).	0	4	8	12	16	20
				100 points max		__________

Figure 9: Rubric For Evaluating Laboratory Inscription Notebooks

explicit instruction regarding scientific inscriptions. During their enrollment in "Just Do It," the students were not given copies of the rubric (Figure 9) used to evaluate the laboratory notebooks. However, the students had since received such instruction in a science methods course and had experience with inscriptions in other courses. Therefore, the primary topic of conversation during the focus group was the participants' experiences with inscriptions and their thoughts on how they could have been used during their "Just Do It" class. A discussion guide (Figure 10) was used to facilitate the focus group.

Miscellaneous Artifacts

Students were asked to provide the author with copies of the research reports they wrote for a part of their course grade. The author retained these copies along with a few other miscellaneous items related to the course. These items include research papers written by the course instructors and other

1. Tell me about your educational background and work experience.
   Prompts as necessary
   - Current degree program
   - Current career goals
   - Previous degrees
   - Previous work experiences
2. When did you take the "Just Do It" course?
3. What stands out in your mind about the course?
4. When did you first learn about inscriptions and hear them called such?
5. Is there a difference between how you've used that concept now verses in "Just Do It?"
6. Ask if they would be willing to read a draft and to leave their address if they are.

Figure 10: Discussion Guide For Focus Group

authors about topics pertinent to the course, copies of all handouts provided to students including the course syllabus (see Figure 3 in appendix), copies of pedagogical items used by the course instructors to generate class discussions and copies of announcements read to the students. Copies of handouts used by the students during class presentations were also retained.

General Data Treatment Procedures

The seven sources of data were constantly being evaluated and considered by the author as the research study progressed. They were used to help the author modify future research patterns and to answer the basic research questions of this study (see Chapter One). Ultimately the data sources were coded or labeled by the author according to the research question(s) they pertained to. They were then analyzed for the presence of consistent themes and redundancies by way of analytic induction and bracketing. Bracketing (also known as reduction) involves the isolation of pure, basic themes from the research data. Such basic themes are reported in their most elementary form, apart from the research situation. Care is taken to avoid applying technical terminology or jargon to the themes at this early stage (Denzin, 1989). During this portion of the analysis, the author participated in a university phenomenology group.

Phenomenology is a philosophical school of thought that attempts to describe basic and essential human experiences apart from predetermined theories or paradigms (Bogdan & Bilken, 1997; Pollio, Thompson & Henley, 1997). The author provided transcripts of a discussion among the research participants (see subsection entitled Videotapes of Class Meetings) to the members of the phenomenology group, mentioned above. The research participants' discussion was centered on their reading of a paper by Barab & Hay (2001) that concerned learning science through apprenticeship. During the analysis, the transcript of the students' discussion was read aloud in small segments while members of the phenomenology group periodically suggested basic themes from the transcript to the author.

The author's experience as a teacher, experience as a participant-observer, and review of the literature (see Chapter Two) helped to guide the total data analysis for this research project. The author also sought to confirm and/or discuss emerging themes with the research participants during the concluding interview (Patton, 1982; 1990) described above. Further, some participants were randomly selected to receive written drafts of preliminary analyses and comment on their accuracy to the author.

<u>Summary of Methods</u>

This chapter has provided an overview of the qualitative methods by which data were gathered for this research project. The methods are grounded in the social constructivist paradigm and rely heavily on the actual words, experiences and products of the research participants. Extended interviews, artifacts from the research participants, reflective journals and other data sources are also described in this chapter. The following chapter, Chapter Four, will present the results of the study.

Chapter Four: Results

This study focuses on four primary research questions concerning a group of preservice science teachers who were learning science through inquiry and being evaluated by a number of alternative assessment techniques. One of the alternative assessment techniques was a laboratory inscription notebook each participant maintained throughout the duration of their enrollment in the "Knowing and Teaching Science: Just Do It" course. This chapter, Chapter Four, will present results of the study. As shown in Figure 11, this chapter is divided into four primary sections. Each section will present and address research findings related to one of the four research questions.

FOUR PRIMARY DIVISIONS OF CHAPTER BASED ON FOUR RESEARCH QUESTIONS

- **Question 1:** What are the experiences of students who learn science through inquiry?
- **Question 2:** What are the experiences of students who are assessed by authentic techniques?
- **Question 3:** What are some examples of scientific inscriptions students record during their experiences?
- **Question 4:** Will participation in an inquiry-based science course, and in the activity of recording inscriptions, improve students' ability to design and carry out successful science experiments over time?

Figure 11: Overview of Results in Four Sections

Question One: What Are the Experiences of Students Who Learn Science Through Inquiry?

Figure 12 presents an overview of the organization of results related to this research question. The experiences of the research participants while learning science through inquiry fell broadly into two categories. The first category included pedagogical experiences related to scientific inquiry. The second category included affective experiences related to scientific inquiry. Both categories of experiences are discussed in detail, with supporting evidence.

Question 1: What are the experiences of students who learn science through inquiry?

I. Pedagogical Experiences Related Directly to Inquiry
- A. Inquiry With C-Fern
- B. Inquiry With Other Organisms

II. Pedagogical Experiences Related Indirectly to Inquiry
- A. Journal Club Presentation
- B. Establishing, Caring For and Observing Mealworm Cultures
- C. Class Discussions

III. Affective Experiences Related to Inquiry
- A. Believed Enrollment in Course Was Unnecessary
- B. Initially Nervous and Uncertain
- C. Believed the Teacher Had Actual Answers and Clear Expectations
- D. Frustration
- E. Felt a Sense of Accomplishment and Progression
- F. Saw Collaboration as Important
- G. Found Their Experiments to be Relevant and Interesting
- H. Believed No Actual or Right Answers Were Known
- I. Found That Science Often Requires Creativity

Figure 12: Overview of Results Relating to Question 1

<u>Pedagogical Experiences Related Directly to Inquiry</u>

The participants had two primary pedagogical experiences relating directly to inquiry. One experience involved inquiry with C-Fern™ and the other involved inquiry with other organisms. Figure 13 presents an overview of the various pedagogical experiences, relating directly to inquiry, had by the research participants during their course enrollment. Both the inquiry experiences, as well as student outcomes related to them, are more fully accounted for in the text.

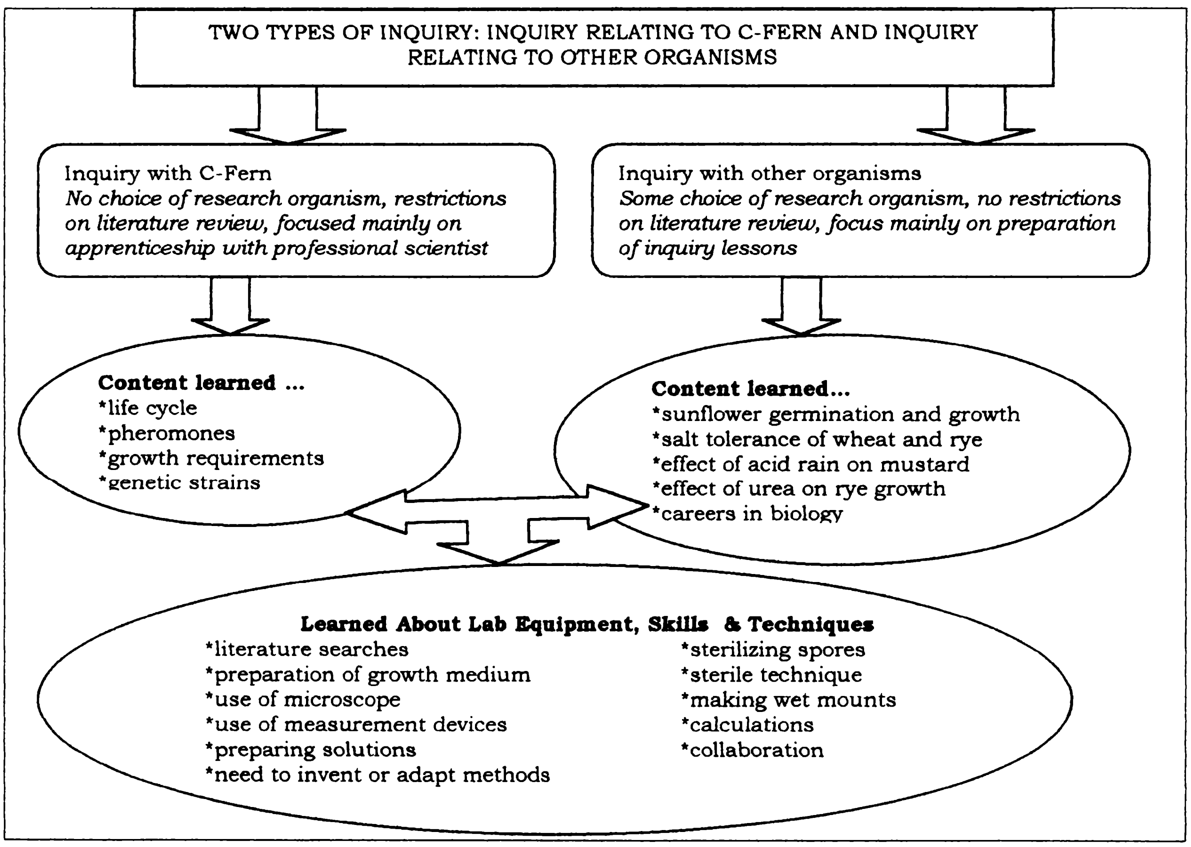


Figure 13: Overview of Pedagogical Experiences Relating Directly to Inquiry

Inquiry with C-Fern™. This particular experience with inquiry spanned about the first nine weeks of the course. C-Fern™ is the name applied to a cultivar of the tropical fern *C. richardii.* Under ideal conditions the life cycle of the fern is less than 90 days. The gametophyte (gamete producing) generation may complete sexual maturation in as little as one week. The organism is easily cultured and requires little care. Further, its reproductive structures are easily observed. In fact, the gametophytic structures are visible without magnification. A dissection microscope or a compound light microscope provides detail. Gametes (cells for sexual reproduction) are visible with magnification of as little as 20 times. Two gametophytic growth forms occur, depending on the concentration of a pheromone-like substance, which the plants secrete. Higher concentrations of the chemical produce mostly male gametophytes. The male gametophyte releases spermatozoa that are chemically attracted to the ova. Lower concentrations of the pheromone ultimately produce hermaphroditic gametophytes that house developing ova. In addition to the wild-type strain, mutant strains of C-Fern™ are also available commercially. Examples include a salt tolerant strain and a strain in which chloroplasts congregate into polka dot-like clusters (Hickok, Warne, Baxter & Melear, 1998; Hickok, Warne & Baxter, 2000).

On the first day of class, students were given ten milligrams of dry wild-type C-Fern™ spores in a vial. Dr. Temple told students that the organism grows best at about 28 °C and that a mineral nutrient growth medium would be furnished. Students were also told to consider their resources unlimited, unless they were told otherwise. They were further asked to refrain from looking at Internet web sites and published literature having specifically to do with the organism. Related to this, the students were encouraged to formulate and use their own vocabulary to describe the structures they observed. Dr. Temple challenged the students to find out something about the organism during class.

Without prompting from any of the instructors, the students broke into four work groups. One student, Phillip, later noted the following in his reflective journal: "It seems like the small groups have formed within the class based on where we were sitting the first day." Each group completed several experiments on the organism. Most students went to work on projects relating to the C-Fern™ life cycle. The group experiments are listed below. Ultimately, the students prepared oral and written summaries of their experiments.

1. Susan, Sara and Basma studied the effect of freezing temperatures on spore germination. They also studied ratios of gametophytes produced in different spore inoculation densities, growth of the two gametophytic forms in isolation, and they studied migration of the spermatozoa during fertilization. They carried out some other work relating to the organism as well.

2. Alice and Veronica looked at whether inoculation density of spores would alter growth rate or form. They also focused their work on what causes the two gametophyte growth forms of the fern. These students also completed other work related to the organism.

3. Phillip, Richard and Greg examined the effect of light exposure on the plant's growth rate and form. They also studied influences on the presence of the two gametophyte growth forms and the migration of spermatozoa during

fertilization. Further, they studied reasons for contamination of their fern cultures and responses of the plant to various levels of light.

4. Morgan and Ralph focused very little on the plant's reproductive cycle. They did set up one study comparing the two growth forms. However, they looked at the growth rate of the plant when grown in culture media with differing concentrations of sodium chloride. As their study progressed, Dr. Temple gave Morgan and Ralph a vial of spores from a genetically salt tolerant strain of C-Fern. He did not tell the students that the strain was salt tolerant but suggested they compare it to the wild-type spore stock. The students identified the second strain as being more salt tolerant by way of their research. Ralph reported that he did not know the plants were salt tolerant "until we started seeing the data."

The C-Fern inquiry also produced a variety of other learning opportunities and related pedagogical experiences. These are listed below.

1. A discussion of genetic ratios. Dr. Temple gave the students Petri dishes that had been inoculated with the polka dot mutant. Initially, he identified the plants as being a "second unknown." Following are excerpts of the resulting discussion among a few of the participants.

> Dr. Temple: These have been sitting out of the light in a box and that's why it's paler. I was hoping you could tell me the difference.
>
> Greg: There are more males.
>
> Richard: Very little pigmentation. Saint Patrick's Day corn flakes! [This term refers to the polka dot hermaphroditic gametophyte]
>
> Dr. Temple: You see the little polka-dot things? What would you hypothesize about their presence on

/// [This symbol means that the speaker briefly pauses or hesitates.] How would you explain the polka dots genetically?

Ralph: Mix it with the other wild types.

Susan: You would need to separate and purify the populations. Are there rice [male gametophytes] with them?

Dr. Temple: What genetic ratio of polka dots to greens [wild type] would you expect?

Several students: Three to one.

Dr. Temple: Why would you expect a three to one ratio?

Phillip: If there has been a cross and one is a heterozygote>>> [This symbol means that the speaker is interrupted by another person.]

Dr. Temple: Well, forget about the rice, they don't have it.

Basma: A one to one ratio? I saw that.

Dr. Temple: So that's your new hypothesis? How would you make them cross fertilize?

Phillip: Put a big batch of polka dots and greens together. That wouldn't necessarily tell you how it happened but you would have a ratio. You could work backward from there.

2. Laboratory techniques. Dr. Temple taught one group of students to mix the C-Fern growth medium and prepare Petri dishes for growing the organism. This group taught the other students the technique. A similar situation occurred as Dr. Temple taught one student to sterilize C-Fern spores with a bleach solution. She shared the technique with others in the class. Another student, Sara, was enrolled in another botany course during the semester. She saw a demonstration in that course in which a chemical, malic

acid, was used to attract C-Fern spermatozoa. She demonstrated this technique to the other students in the "Just Do It" class. Finally, the students made wet mount microscope slides, used nucleic acid stain and learned to sterilize laboratory equipment by exposing it to a flame.

3. Use of laboratory equipment. Students used dissection microscopes, light microscopes and calibrated microscopes for measurement. They used balances, graduated cylinders and other equipment. It is of particular note that some of the students had trouble with the microscope. The compound light microscope is, arguably, one of the most basic and essential tools of the biologist. One exchange, with the author, relating to the use of the microscope occurred as Greg was involved in helping other students to construct details of the C-Fern™ life cycle. Specifically, he was working with the male gametophyte [rice] and the hermaphroditic gametophyte [corn flake] Some of the other students had problems similar to Greg's, the basic operation of the microscope.

> Greg: Is the image in a microscope /// is it like flip-flopped? Do you know what I'm saying?
>
> Eddie: It's inverted and reversed. [Eddie moves the stage adjustment knobs on Greg's microscope] If you move it this way /// see? The image is actually going to move toward you. And if you move it even to the left /// the image goes to the right.
>
> Greg: Oh. I can't figure out in relation to /// these /// the rice and the corn flake ///to each other. Which direction do they ///
>
> Eddie: Well, go back. What you might want to do, and I know you're probably trying to do this quickly /// But go back to your lowest power objective and get a bigger picture in your mind. Then magnify higher.
>
> Greg: Ah, there it is.

4. Use of published reference material. As previously noted, students were explicitly asked to refrain from looking at published materials related to C-Fern™. The instructor did provide some general botany texts that included generalized fern life cycle diagrams. The students referred to these texts on several occasions. One student, Susan, brought a book containing research papers on ferns and fern allies to class. She reported to the author that she got the idea for an experiment involving germination of frozen spores (see above) from a research paper printed in the book.

Inquiry with other organisms. This second experience with inquiry began about the tenth week of the course and continued throughout the remainder of the sixteen-week semester. The reader may again refer to Figure 13 for an overview of the inquiry experiences had by the students. As the inquiries with C-Fern™ were drawing to a close near the middle of the semester, Dr. Taylor and Eddie began to prepare the students for the second round of inquiry. Eddie began by asking the students to consider the work they had done up to that point and to suggest a list of things that help to make a good experiment. He wrote the students' suggestions and responses on the board. The resulting list is shown in Figure 14.

* keep the experiment simple
* adequate sample size
* make inscriptions
* need a control
* make experiment repeatable
* hypothesis should be simple and testable
* cheap and inexpensive materials are often best
* need to have operational definitions

Figure 14: Student Responses "What Makes A Good Experiment?"

Dr. Taylor made a wide variety of plant materials available to the students. Several types of seeds including rye (*Lolium*), wheat (*Triticum*), sunflower (*Helianthus*), crimson clover (*Trifolium incarnatum*), loblolly pine (*Pinus taeda*) and mustard (family Brassicaceae) were brought to the lab. In addition to this potting soils, cups, and other containers were made available.

The students were given minimal guidelines but they were instructed to complete at least one inquiry, using the available materials as a beginning point. Further, the students were asked to prepare a lesson, suitable for students in grades 7-12, based on their inquiry work. They were asked to use the 5 E learning cycle (Trowbridge & Bybee, 1995) as a pedagogical basis for their lesson. A skeleton description of the basic steps of the 5 E model follows. (1) Engage. The teacher introduces the students to some question or problem. (2) Explore. The students begin an activity in which they inquire into the question or problem. (3) Explain. The teacher helps students to clarify their understanding. (4) Elaborate. The students build upon their understanding on the question or problem. (5) Evaluate. The students' understanding of the question or problem is assessed (Trowbridge & Bybee, 1995). The experiments and lessons prepared by the participants in this study are summarized below.

1. Basma, Sara and Richard focused their work on the sunflower. In one experiment, they studied the effect of seed position in the soil with regard to germination. In this case, the apex of the seeds in each experimental group was pointed either up, down or laterally with respect to the soil surface in the potting containers. The students carefully tracked germination and growth rates over the course of several days. In a second experiment, they studied the

effect of hot and cold temperatures on plant growth. For their inquiry lesson, this group gave materials to the class to work with and asked the student work groups to devise experiments to determine how germination of the seeds could be hastened.

2. Morgan and Ralph continued their work with salt tolerance in plants (see above). For the second portion of their inquiry, however, they worked with wheat and rye. They compared the growth rates of both plants when watered with sodium chloride solutions of varying concentrations. For their inquiry lesson, they asked each student work group in the class to contribute to a mock experiment. One group of students made sodium chloride solutions, a second group prepared potting soil and planting containers, and a third group was asked to find a way to distinguish between young wheat and rye plants. Further, Ralph and Morgan asked all student in the class to prepare a graph using data points from the experiment, which they provided to the class. They provided each student with graph paper but gave no further instructions. Table 2 shows an excerpt from the resulting class discussion and activity session. This transcript was extracted from videotape. As can be observed in lines two through nine (Table 2), the students found that various types of graphical inscriptions may be used to present various types of experimental data. The students found that the choice of graph may depend on what thing(s) the researcher is trying to call attention to. Further, the students demonstrated competence and understanding regarding the interpretation of basic data trends from a graphical inscription (lines 10 - 12).

Table 2

Discussion of Graphical Depiction of Data

AUDIO TRACK	VIDEO TRACK
1. Morgan: Don't forget the importance of labeling your graph.	Morgan & Ralph circulate among the students while the class makes graphs.
2. Morgan: I'm noticing that not everyone did the same type of graph. We're doing these graphs to show trends.	Morgan holds up a line graph drawn by a student in the class.
3. Morgan: Does a graph like this show a trend?	
4. Various Students: Yes	
5. Morgan: And does a graph like this show a trend?	Morgan holds up a bar graph drawn by another student in the class.
6. So both of these are fine?	
7. Dr. Taylor: So you wouldn't want a pie graph?	
8. Morgan: Not for this. It doesn't show trends very well.	Several students nod "yes."
9. Ralph: So what does this graph tell us?	
10. Several students speak at once: The wheat grew better.	Ralph completes a line graph on the dry erase board & turns to the class.
11. It is more salt tolerant.	
12. With increasing salt you get less growth.	

3. Susan, Phillip and Greg were interested in acid rain. They studied the effect of four different solutions of sulfuric acid, at different pH levels, on the growth and germination of mustard plants. For their inquiry lessons, these students asked the class to observe plant material from their experiment and suggest possible conclusions. Further, they asked the students to measure pH levels of various water samples (some from local water sources shown on a map these students provided to the class) using both commercially prepared pH paper test kits and an electronic pH meter. They asked each group to verbally summarize their observations.

4. Veronica and Alice studied the effect of varying concentrations of urea on the growth of rye. Urea is an ingredient often used in commercial fertilizers. For their inquiry lesson, they devised a scenario in which a farmer living near a new subdivision began having problems with his crop yield. The two students gave the class samples of the plants they grew in the various concentrations of

urea and asked the students to suggest where the plants might have grown, using a map (Figure 15) correlated with the scenario. Finally, they asked the other students to role-play the points of view of farmer, agricultural extension agent, attorney and real estate agent.

Like the inquiry with C-Fern™, the inquiry experience with other organisms and the resulting lesson presentations fostered several learning opportunities and pedagogical experiences. Some examples are listed below.

1. Practice making graphs. See Table 2 and the above subsection describing Morgan and Ralph's experiments.

2. Practice making laboratory solutions. In three of the inquiry projects, students had to prepare chemical solutions. Some solutions varied by millimolar concentrations of sodium chloride, others by percent of urea and others by pH level. Students calculated and prepared amounts of reagents required for the solutions.

3. Use of published reference material. In the inquiry lessons, the students were at much greater liberty to review literature and consult other published sources. Each group reported they had done so. Professional research papers, Internet pages, monographs and textbooks were used. In this case, the review of published materials seemed to precede actual experimentation. In other words, most of the students did some sort of a literature review before beginning their next set of inquiry projects. Examples to support this conclusion are shown below. These excerpts were extracted from video transcripts and from student reflective journals.

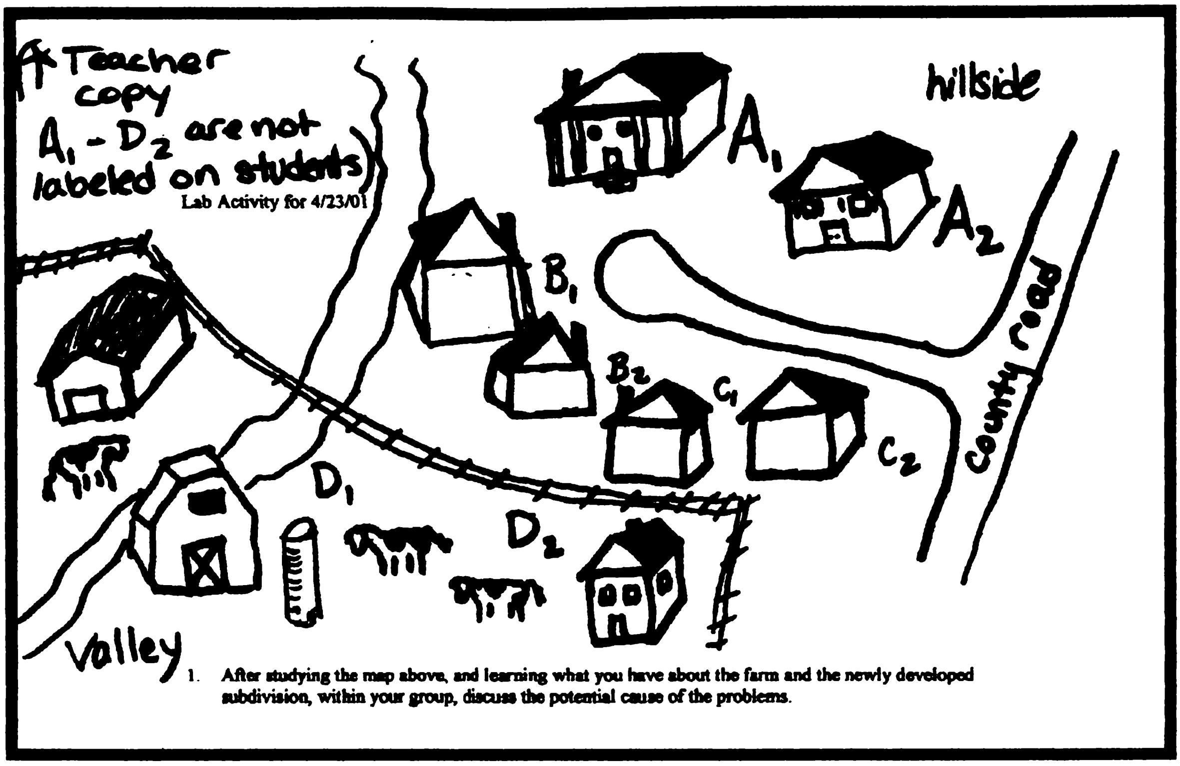


Figure 15: Alice & Veronica's Lesson Presentation Map

Susan: We mixed up sulfuric acid. We selected four because the literature seemed to say that 4.3 is about the worst acid rain that's prevalent in the United States right now. It seems like the acid rain in [a regional National Park] runs about 4.3. That figure came from the Environmental Protection Agency Web site.

Basma: We had a little problem at first. We couldn't decide between sunflower seeds and crimson clover. So, we did some research in the library. But we ended up with nothing. (laughs)

Sara: We went to the library to research the two plants and came up with nothing. The only literature we found was on the sunflower. We found at least one or two books on sunflowers in the library. We did some Internet research on sunflowers. We were basically going to keep it really, really simple. We just now planted the seeds.

Alice: Our intention is to find a logical pollutant to demonstrate the damage that is done to grass or agriculture. We are still trying to research the best, most logical pollutant that might effect grass in the real world. I recorded a lot of research of nitrogen and the effects of alkaloid poisoning from rye grass for animals from the Internet.

Phillip: We did a little research and found the sulfuric acid is one of the most common forms of acidic rain currently today. So we decided to simulate acid rain by mixing sulfuric acid and water into four solutions. We had a variety of seeds to choose from and we just happened to pick up a packet of mustard seeds. We did a little background check on the plant and found it was one that grew relatively fast and was quiet hearty. We thought it would be a perfect match for the experiment so we decided to use it.

Pedagogical Experiences Relating Indirectly to Inquiry

Some other pedagogical experiences relating to inquiry in a more indirect fashion were also had by the research participants during their course enrollment. These experiences include presentations, discussions and a long-term observation of mealworms. The pedagogical experiences relating indirectly to inquiry, and the student outcomes related to them are overviewed in Figure 16. Discussion of specific pedagogical experiences related indirectly to inquiry are presented within the text in the following subsections.

Journal club presentations. This experience occurred during the fifth and fourteenth week of the term. The students were first asked, by Dr. Temple, to search the scientific literature and find a copy of a published research paper, relating to biology, that they were interested in. They were further asked to provide a very brief oral summary of the paper and a critique of the methods described in the paper for the class. Particularly, students were asked to focus

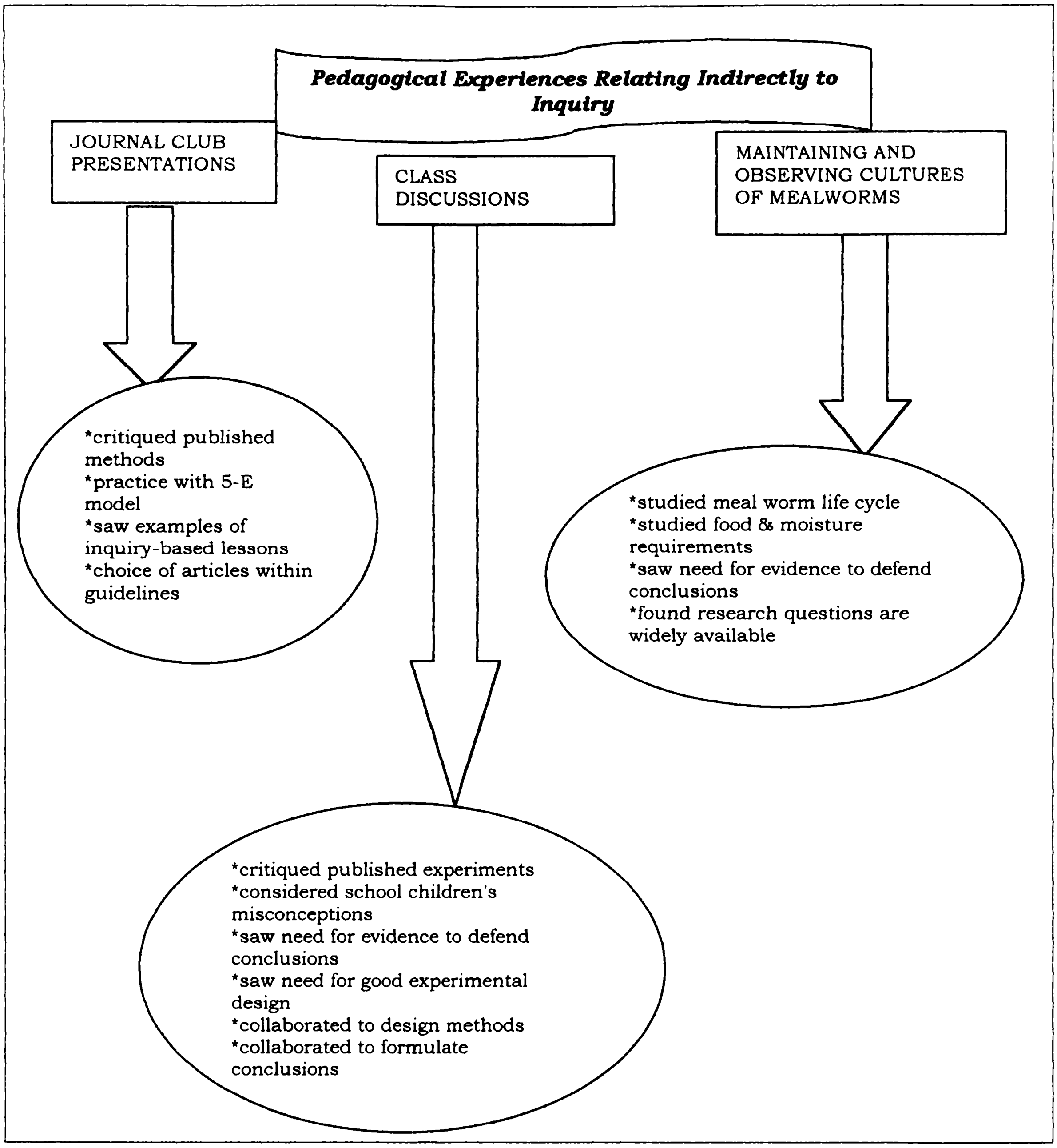


Figure 16: Summary of Pedagogical Experiences Relating Indirectly to Inquiry

on experimental design, conclusions stated compared to evidence, and how results were presented by inscriptions. The students selected papers on topics ranging from chimpanzee vocalization to rheumatoid arthritis drugs to the role of mycorrhizal fungi [those which live in association with the roots of certain plants (Alexopoulos & Mims, 1979)] in success of grasses grown at golf courses.

For the second assignment, Dr. Taylor asked the students to find a paper in the educational literature that described an inquiry-based lesson which had the "Five E" learning cycle, a pedagogical model (Trowbridge & Bybee, 1995), as its basis. The students were again asked to present oral summaries of the papers to the class. This time, however, the focus was on ideas for inquiry-based lessons and how the "Five E" model is used. Five students selected review papers on the topic of teaching by inquiry. Other students selected papers that described specific inquiry-based lessons involving, for example, various seeds, leeches, local plants and weather patterns.

A few of the students commented on the journal club presentations in their reflective journals. Some comments relating to this experience are shown below.

> Greg: I did feel that I picked an article that everyone could understand. In fact, the data collection for this article was so poor, I found it easy to critique it, which is the point of the exercise.
>
> Phillip: Overall, I think the presentations were good. Some of them were a bit dry. Each presenter made good observations on the strengths and weaknesses in their research, and the class as a whole did fine in distinguishing proper methods for research and experimentation.
>
> Basma: I think in these journals we get to see the real procedures that real scientists go through and how

> they come about forming experiments and hypotheses. Also from this we can see that we are going through the same processes they went through, therefore making all of us real scientists.

Establish, care for and observe a mealworm culture. During the tenth week of the term, Dr. Taylor gave each student several mealworms (*Tenebrio*) and some culture medium in which to keep them. "Mealworm" is the common name given to the larvae of various darkling beetles, of the family Tenebrionidae, that tend to feed on various types of stored grain. Like all beetles (Order Coleoptera) *Tenebrio* exhibit a holometabolous life cycle in which metamorphosis is complete. Sexually mature adult beetles mate. The fertilized ova develop into a series of ever-larger larval instar substages. These larvae are highly active and motile. The organisms then develop into pupa which are enclosed in a hardened puparium. The pupae are inactive until breaking free as adult beetles (Borror & White, 1970).

Before beginning this activity, Dr. Taylor asked each student to bring a suitable container to class to house their mealworm cultures. Initially, no detailed instructions or assignments related to the mealworms were provided. The students were simply told to "baby sit" these cultures and to observe them. Ultimately, the mealworms were to be used for inquiry-based work in a course the students were scheduled to enroll in two semesters later. Some students recorded inscriptions relating to the mealworms (see the section on inscriptions, below). Further, some interesting learning experiences occurred as the students cared for and observed the mealworm cultures. Table 3 presents some excerpts from a class discussion involving the mealworms. In the exchange occurring in lines one through five, notice that Dr. Taylor encouraged Veronica to present evidence for her claim that her mealworms were dying. In lines 12 and 13, she refrained from "giving an answer" to Susan about the life cycle of the mealworms. Further, Eddie and Dr. Taylor tried to encourage students to observe or investigate on their own to satisfy their questions. Dr. Taylor, again while trying to refrain from giving away an answer the students asked for, asked the class "What's going to happen here?" (line 17). Also of note is the fact that the day before, a student reported to Dr. Taylor that he had found a live adult beetle in his culture. He told her that he thought it either fell in or

Table 3

Excerpts From Discussion About Mealworm Cultures

AUDIO TRACK	VIDEO TRACK
1. Eddie: Say something about your mealworm cultures. Bring us up to date on that.	Eddie is speaking to Veronica & Alice.
2. Veronica: Well, I've got some that have died.	
3. Dr. Taylor: Why do you think they are dead?	Veronica removes a pupal case (puparium), probably containing a live organism, from her culture.
4. Veronica: They are dark in color & dry.	
5. Dr. Taylor: Could be from lack of moisture. I found some good sites on the internet. One said the best way to grow mealworms was just to watch them; to just observe.	
6. Morgan: The shedding kind of scared me for awhile. Because there were all those exoskeletons. I thought "Oh what did I do?" It played tricks with my mind.	
7. Susan: As for our mealworms, Phillip is good at growing mealworms. His are fat & juicy.	
8. Phillip: They've changed a little bit. They're really big & fat. Started getting legs & stuff.	Phillip removes a mealworm from his culture container.
9. Dr. Taylor: Well let me ask you this, all of you. Have you studied metamorphosis before? Have you studied it with a living animal?	Several students nod their heads "yes."
10. Greg: I think we did, with a caterpillar.	
11. Ralph: Butterflies & tadpoles...	
12. Susan: So what are you getting at? Is this getting ready to change into something?	Several students laugh, then become silent & look toward Dr. Taylor.
13. Dr. Taylor: Well is it something that would metamorphose? That's the question.	
14. Susan: I was thinking that was actually a baby that would turn into a mealworm.	Susan points toward Phillip's culture.
15. Dr. Taylor: That is a mealworm.	
16. Eddie: That's a very interesting question.	
17. Dr. Taylor: Yea. What's going to happen here?	

that it came from within the culture. This student later wrote the following in his reflective journal:

> Morgan: I learned some valuable information about my meal worms. For the longest, I have thought that my worms have been drying out and dying. This was so wrong. I learned that they shed their exoskeleton in order to grow. I had never considered that to be what was going on.

Class discussions. Class discussions were a routine affair in the "Just Do It" course. Discussions occurred within and among the cooperative work groups. Some discussions were led by course instructors and/or by teacher assistants. Some discussions were informal and others were very topically focused and formal. Some specific examples of the various types and outcomes of class discussions are described below.

1. Critique of published experiments. As noted above in the subsection entitled "Journal Club Presentations" students had the opportunity to read, discuss and critique published research papers on science topics of their choice.

2. Discussion of a public school student's science fair project. During the third week of class, Dr. Temple presented the students with a copy of an electronic mail message that was distributed through a list server. The message (Figure 17) came from a student working on a science fair project. She was requesting help with reference material and listed a summary of her science fair project. Dr. Temple used this e-mail as a pedagogical tool to initiate a discussion of the student's experimental design. "This is true. I get these all the time." He said. "How would you respond?" Some comments from the

Sent by ____
To: ____
Subject: Help

Hello, I need some help. For my science fair project I am growing three plants. One is being watered with water, one with soda, and one with vinegar. The problem is I haven't found any books in the library about it. Could you help me find a book about it? I need at least 2. Thank you!
From, ___

Figure 17: Electronic Mail From Public School Student

participants are also listed below in order to clarify their experiences with this discussion activity.

> Susan: Define "it." What are you looking for?
>
> Phillip: Is it the same plant? I'd want to know that. Also, I'd ask "What's your hypothesis?"
>
> Basma: What do you want the books on?
>
> Richard: I think she needs help with her method and controls.

3. Verification of Findings on C-Fern™ Inquiry. In these instances, Dr. Temple asked the students to discuss, as a class, the findings they had arrived at and the data they had to defend their findings and conclusions. Table 4 presents a transcript of one of these discussions. This particular discussion focuses on the students' findings about the C-Fern™ gametophyte generation. During the conversation, Dr. Temple placed great emphasis on the need for scientific evidence to back up a conclusion offered by the students. Specifically, lines six through 12 and lines 18 - 30 demonstrate that Dr. Temple repeatedly asked students for evidence to back up their conclusions. He asked for details on their methods, sample sizes and other experimental variables but refrained from verifying very many details.

Table 4

Discussion of C-Fern Gametophyte Generation

AUDIO TRACK		VIDEO TRACK
1.	Dr. Temple: I want you to chat. Start at the beginning, the simplest stage of the organism. What happens to the unknown? Elaborate on this & go through the biology.	Dr. Temple speaks to entire class
2.	Alice: Well, we've found a difference. There are two growth forms, the rice [this term refers to the male gametophyte] & the corn flake [this term refers to the female gametophyte].	
3.	Susan: What was your control & your results?	Speaks to Alice
4.	Dr. Temple: So, a genetic difference between the rice & the corn flake?	Dr. Temple speaks as Alice is looking at her laboratory inscription notebook. Speaks to Greg
5.	Greg: Yes.	
6.	Dr. Temple: How would you prove that?	
7.	Greg: There is a larger production of the squiggles [this term refers to spermatozoa] which we determined are the gamete in the rice. They proceed to the corn flake.	
8.	Dr. Temple: So what about a genetic difference? You're describing a difference in terms of squiggle production.	
9.	Morgan: There wouldn't be a genetic difference but different transcribing /// genes being expressed.	
10.	Dr. Temple: Anybody proven that? Mendel's difference?	Dr. Temple speaks to the entire class.
11.	Alice: You'd see a developmental difference if it was genetic. We didn't.	
12.	Dr. Temple: Right, you've proven that it's not a genetic difference. It's a simple experiment but it answered a huge question.	
13.	Greg: Say that again.	
14.	Susan: He's saying if it had been a genetic difference, you would have gotten some variety in rice & corn flakes.	
15.	Sara: It seems to be environmental, the difference.	
16.	Greg: How many did you do?	
17.	Alice: I think 18. We used 18.	Speaks to Alice.
18.	Dr. Temple: Do you think that's enough?	
19.	Greg: Well, according to our results it would be. It was consistent.	Dr. Temple speaks to Alice.
20.	Dr. Temple: So, what's your sample size?	
21.	Greg: Eighteen	Speaks to Greg.
22.	Richard: Theirs was 18. Ours was 60. Six dishes with ten spores. They are showing there must be some type of chemical reaction or something to have rice occur with corn flakes.	Greg looks at his laboratory inscription notebook.
23.	Dr. Temple: What was their treatment?	
24.	Richard: Their treatment was one spore in a dish of agar by itself. They had 18 individual dishes. Ours was 10 spores in six dishes.	
25.	Dr. Temple: What was your treatment?	
26.	Richard: We simply put sterilized spores in each dish.	
27.	Dr. Temple: How many times did you do that?	
28.	Richard: Six times.	
29.	Dr. Temple: So, what's your sample size?	Speaks to Richard.
30.	Richard: Sixty /// well /// ten per dish.	
31.	Ralph: I think it's six because theirs no way you can control any chemical reaction inside of that dish.	
32.	Richard: But that's not what we were testing for. We had no idea that there was a chemical reaction. We were testing for a ratio difference between rice & corn flakes occurring in a dish.	Speaks to Ralph.
33.	Dr. Temple: N equals six. But you've got 10 per dish. Which is good. Six different populations of 10 individuals. So, it gets a little tricky. I'm glad that came up. So, you've shown convincingly this is not a genetic difference. The next option is what you suggested, a chemical? How would you test that?	Speaks to Richard. Speaks to whole class
34.	Alice: It's our opinion that rice or corn flake is already present but one exudes a chemical that will make the other spore turn into a corn flake.	
35.	Dr. Temple: Will your experiment prove your idea there is a chemical?	Speaks to Alice
36.	Alice: It will prove there is some kind of mechanism. It won't necessarily prove that there's a chemical.	

Instead, he asked students how they could prove or demonstrate (lines 6, 10, 35) what they were claiming, by way of scientific evidence.

4. Group Discussion of Inquiry Experiences With Other Organisms. During these discussions, Dr. Taylor and Eddie asked the students to summarize the initial work they had done regarding their inquiry experiments. Students were encouraged to share their ideas with each other and to make suggestions and comments to one another regarding their on-going work. Table 5 provides selected excerpts of transcripts extracted from videotapes regarding these discussions. As can be observed from the transcript, the discussion focused on coming up with novel methods and procedures (lines eight and 32 - 33), the need for evidence to back up conclusions, importance of sample size (lines 38 - 44), the occasional need for pilot studies (line eight), reasons for doing scientific experiments and possible future extensions of experiments in progress. It is of note that a collaborative atmosphere tended to dominate the discussion. Notice that in line three, Alice described some of the experimental questions she had considered and then asked the class, "Do you all have any ideas?" In lines 32 and 33, a similar situation unfolded as Dr. Taylor and Sara discussed one group's problem of controlling light exposure when temperature was their experimental variable. Once again, the instructor and teacher assistant tried to give hints and suggestions to students but made an effort to refrain from giving away answers or insisting on the use of specific methods (lines eight and 17 - 31).

Table 5

Discussion of Inquiry Experiments (continued on next page)

AUDIO TRACK	VIDEO TRACK
1. Eddie: Why don't each of the groups summarize what they've done so far with their experiments?	Eddie speaks to entire class.
2. Have you thought about what your experimental variable will be?	Speaks to Alice.
3. Alice: That's one of the things that we're really working on because I want it to be something that really is out there that people really do use. Possibly even a fertilizer, maybe one that's overly used. So, I'm not really sure. Do you all have any ideas?	Speaks to entire class.
4. Susan: You could compare manure to fertilizer.	Speaks to Alice.
5. Eddie: That's very interesting; a natural fertilizer verses a synthetic.	
6. Dr. Taylor: Do you know what's in fertilizer?	
7. Alice: Well it depends on what kind you've got. Some are nitrogen based. Some soils are deficient or rich in certain chemicals.	
8. Dr. Taylor: I would also suggest that if you don't see changes [in your plants] above ground that you might check the roots because these compounds might effect parts of the plant that are not visible from the ground up. Also, I would suggest that once you decide what your variable is going to be that you do a little pilot study so that you don't use everything up. These little pilot studies help you see if you're going to get anything. Try a dilute & then a concentrate. In other words, one may kill it. Then you'll know you might have to dilute it if your concentrate kills it. Do a pilot before you do it full range.	Looks toward entire class. The discussion continues, eventually Dr. Taylor speaks to the second group (Greg, Susan & Richard).
9. Dr. Taylor: About your acid rain study; what kind is it?	
10. Greg: Sulfuric.	
11. Dr. Taylor: Have you actually put any on the seeds or will you wait till they germinate?	Susan points to her group's growing plants.
12. Susan: No we actually wanted to see if it effected germination. So we started from the very beginning & we got some growth. We started growing on Wednesday & they had germination on Saturday. They germinated very quickly. We've got all strengths growing but not all at 100 percent growth.	
13. Dr. Taylor: Ok, so your hypothesis is what?	Speaks to Susan, Greg & Phillip.
14. Susan: Well we think that as the pH is lowered, that we're going to reduce germination & growth of the plant.	
15. Dr. Taylor: & how does that relate to the soils here [in this state]? Are they acidic or basic or do you know?	
16. Susan: Our plan is to do some testing. We weren't really thinking about soil but just looking at the different water. We thought about testing the rain, the creeks, testing the lakes & ponds in the area.	
17. Eddie: Well, I love your experimental design & question but I want you to think about what we talked about, comparing>>>	Speaks to Susan, Greg & Phillip.
18. Susan: Yea, Eddie wants us to consider comparing the loblolly pine. He said this was a pine they're planting in [a local national park]. So we wanted to find out how they germinate.	Susan picks up a package of seeds.
19. Greg: Are they claiming it's just as hardy?	Speaks to Eddie.
20. Eddie: That particular species has been planted for years & years. It was partly experimental & partly reforestation. I'm just sort of curious to know if acid rain has an effect on natural reforestation over time. I don't know if there's any literature on that.	Speaks to entire class.
21. Do you all have any questions for this group?	
22. Ralph: Are you going to mist the plants?	Speaks to Susan.
23. Susan: No, just watering directly.	
24. Dr. Taylor: How are you going to germinate the loblolly?	Speaks to Susan, Greg & Phillip.

Table 5 (continued)

AUDIO TRACK	VIDEO TRACK
25. Eddie: Whenever I mentioned that, I don't necessarily think you need to add that to the experiment you've got going on now. I just think that might be an interesting extension of your findings.	Speaks to Susan, Greg & Phillip.
26. Greg: I personally would like to see how it coincides.	
27. Dr. Taylor: You might want to look up how long it takes a pine seed to germinate.	
28. Greg: Is it the size of the seed that makes it take longer?	
29. Dr. Taylor: I don't /// I'm not saying that. Think of a pumpkin seed. It's larger but it germinates pretty quick.	
30. Susan: Their sunflower seeds germinated quickly too.	
31. Dr. Taylor: All these are experimental questions. There are experiments all over the place for your students. You just have to give them little hints.	
	The discussion continues & eventually the third group (Sara, Richard & Basma) begins their summary.
32. Sara: The seeds that were planted pointing up have actually germinated faster. And the other question we were talking to Eddie about is we were actually going to subject the plants to different whatever. We were maybe going to do hot verses cold conditions. Kind of practical as if you were growing a garden, when do you need to plant? What our main question was is there a place we could grow them in cold temperatures but still have light? Because if you put them in a refrigerator, the light is going to go off when you shut the door. So that's our question.	
33. Dr. Taylor: You could always put...those little lights...What are they called? That, or even inside & outside a window or sliding glass door. You kind of have to invent all these ways of doing experiments so that you know you only have one variable.	
	The discussion continues & eventually the fourth group (Morgan & Ralph) begins their summary.
34. Morgan: We have two different organisms. We have wheat seeds & we have rye seeds. We put two seeds in each cup & we've got ten different cups that have zero millimolar concentration of salt, 10 cups at 50 & 10 cups at 100 & 200. We're checking to see if the seeds have a favorite concentration of salt that it will grow at.	
35. Dr. Taylor: Why salt?	Speaks to Morgan & Ralph.
36. Ralph: Well, you know in the hurricane back in '98 down in the [Florida] keys, after it blew through, everything was brown. So we just tried to think if they needed to grow something down there or if they needed a different yard, what could they grow?	
37. Dr. Taylor: Very good, economic applications! You know so much science is done because it needs to be done.	
38. Eddie: Your dependent variable is growth. What do you mean by that? What's your operational definition of growth?	Speaks to Morgan & Ralph.
39. Ralph: If it's green & above the soil, we measure it.	Speaks to Eddie.
40. Dr. Taylor: I was curious about your number of replicates. Only one per cup? How many?	Speaks to Morgan & Ralph
41. Ralph: No two per cup.	
42. Dr. Taylor: But they're two different?	
43. Morgan: No, four per cup total.	
44. Dr. Taylor: So you have two replicates in each cup?	Morgan nods "yes."

5. Collaborative Construction and/or Verification of Findings. In several instances, students in the "Just Do It" course worked collaboratively to construct knowledge or verify their findings. One of the most interesting examples took place as the students first began to observe emergence of C-Fern™ spermatozoa and their migration. At the same time, other students saw the emerging sporophyte generation of the C-Fern™. The students said that they named the young sporophyte, emerging from the hermaphroditic gametophyte, a "durante" because, they said, it reminded them of the actor Jimmy Durante's characteristically large nose. Table 6 presents a series of excerpts from the transcript of this discussion. This lengthy, but edited, discussion will be referred to numerous times, and in numerous contexts, in this chapter and in Chapter Five. Therefore, it is presented in the appendix. During this detailed exchange and collaboration, some students mistook developing vascular tissues for spermatozoon transport canals. Every effort was made on the part of the course instructors and teacher assistants to allow students to resolve these disagreements on their own, based on evidence and observations. Dr. Temple explicitly or implicitly asked students for evidence to support their claims or conclusions more than twelve times during the lengthy discussion. Notice that in line 10, he asked Susan, Sara and Basma to think through a possible experiment to verify their hypothesis about the C-Fern™ life cycle. Eddie also encouraged the students to think in terms of evidence in lines 132 - 136 as well. Of additional note is the fact that most of the students began to be sidetracked on a "wrong" pathway. Notice that in line 66, Richard first mentioned "canals." He and some other students misidentified these structures

as transport canals for spermatozoa. In actuality, they were observing vascular tissues within the fern. Rather than telling the students that they were "wrong" Dr. Temple and Eddie tried to allow the students to work through their misunderstanding. Hints were given (lines 120, 132 - 236, 216 - 227, 232 - 241), collaboration was encouraged (lines 73, 144, 164) and evidence was demanded. Finally, the students themselves began to more carefully examine their own thoughts and lines of evidence before they presented them to Dr. Temple. During the exchange in lines 200 - 217, several students were collaboratively considering their existing evidence. Notice that as Sara and Susan explained their line of proof (lines 205 - 209), Greg twice asked for more proof. He even said that Dr. Temple "will want to know how we know" (line 215). Ultimately the students resolved the issue. Susan spoke of the need for replication and evidence in lines 252 - 256. Richard later noted to Eddie that he had abandoned his "canals as sperm transport mechanisms" hypothesis.

Affective Experiences Relating to Inquiry

Figure 18 presents a summary of the affective experiences, relating to inquiry, had by the participants during their enrollment in the "Just Do It" course. These affective experiences relate to the students' emotional perceptions of their experiences. Details on the affective experiences are provided below. They are arranged in more or less chronological order.

Believed their enrollment in the course was unnecessary. On numerous occasions, Dr. Taylor has reported to the author that many students seem initially resistant to the suggestion of enrolling in the "Just Do It" course. She stated that this group of participants was mostly resistant as well. All

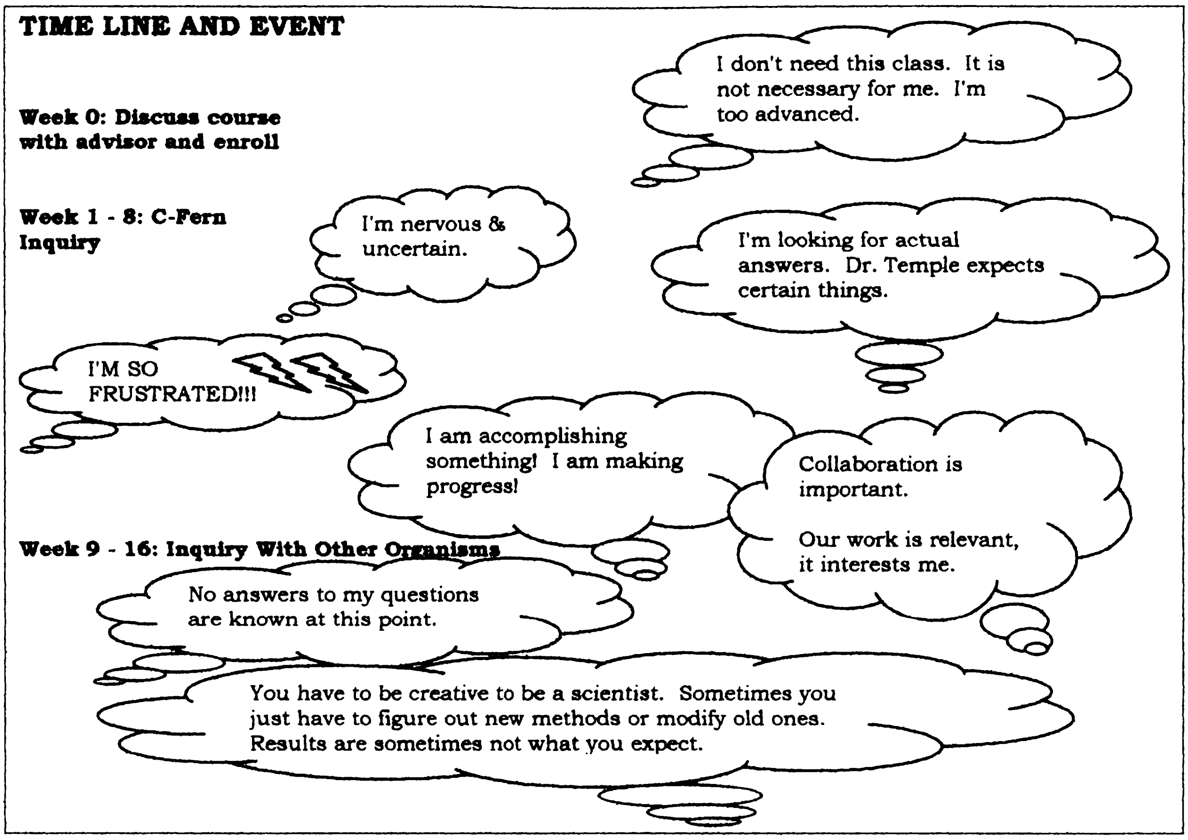


Figure 18: Summary of Affective Experiences Relating to Inquiry

participants, with the exception of Susan, seemed reticent to discuss this emotion further with the author or to provide details to Denise in their reflective journals. Susan's comment, from her concluding interview, is reported below.

> Susan: At first I didn't think I needed it. I did not want to take this course when Dr. Taylor first mentioned it. I just thought I was being forced to take something I didn't need. Now, in retrospect, I don't think that.

Initially nervous and uncertain. All of the participants used adjectives such as nervous, uncertain and unsure to describe their earliest direct experiences with the "Just Do It" course. These emotions are probably common to most everyone entering a new experience. However, the students seemed particularly apprehensive while sorting through their newly acquired roles in the course. Phillip admitted uncertainty but focused less on being nervous (see below). He talked about his "newfound freedom" in the course. Supporting comments from interviews, reflective journals and videotapes are listed below. The participants' own words are used heavily to help clarify this aspect of their experiences.

> Sara: I would say I felt nervous because I didn't know what to expect and if I'd be any good at it.
>
> Greg: I think the biggest frustration was just initial /// We didn't have a clue what we were doing but it got better.
>
> Sara: It definitely took me by surprise because I didn't really know what to expect going into this class either. You can't /// I mean you can't really get the entire gist of the class just by looking at "Knowing and Teaching Science: Just Do It." Now it makes sense, but going into it you really have no idea what you're in for. But I think it's essential for future teachers to take this class.
>
> Greg: I felt kind of lost in the beginning. [Eddie asks "I wonder why that is? In your other classes>>>"] That's why it is. Because you didn't do this in other classes, this is real science whereas you weren't doing science, you were listening to a lecture.
>
> Morgan: My fears about the class increase. All of my school career I have not done very well when it was a student centered setting. I always did much better when the teacher spoke and I acted. I was in for a big change. As we got into class and were handed the vials of the unknown, my brain began to race on how I was going to do research on this.
>
> Alice: It was a little strange when we received the "unknown" from Dr. Temple with no formal further instructions. Veronica, who sat next to me, was also uneasy with the lack of directions. The only official instruction was to "find something out about the unknown."

> Phillip: Once you get through the initial period of the first week or so you understand what your role is and what you need to be doing. I have never been in any class quite like this. I like the idea of being able to run any experiment I want, and at any time I want. This is a newfound freedom that I have never had before in my education here.
>
> Basma: Dr. Temple and Dr. Taylor started to tell us what the class was going to be like and said that we could do any kind of experiment we wanted with the unknown. I guess that is when I became kind of scared because I am so used to the teacher telling me everything that I need to do and when it is due. After a while I joined Susan and Sara who I think calmed me down because this way I wouldn't have to do all this alone.
>
> Veronica: I really don't know what to expect from this class and that bothers me.

<u>Believed the teacher had actual answers and clear expectations relating to the C-fern inquiry.</u> Most of the students seemed to understand that the inquiry with C-Fern did involve verification of information about the organism that was well known to Dr. Temple and other researchers. They also indicated that Dr. Temple had expectations about what constituted good and acceptable research methodology. At first the freedom of inquiry and Dr. Temple's definitive ideas about what counts as good research may seem paradoxical. Students had freedom but yet they were expected to get to a correct answer with procedures that professional scientists, such as Dr. Temple, regard as correct and acceptable. A member of the phenomenology group the author participated in during the data analysis for this project suggested the phrase "freedom within boundaries" to amend this paradox. Again, a sampling of the participants' responses is presented below.

Susan: There were things about the C-Fern that Dr. Temple wanted us to know and figure out. There were answers we were supposed to come up with but there were different ways. Dr. Temple, because of his advanced studies, I saw him as an expert.

Ralph: [Our] experiment is in full swing and progressing nicely. That is to say the results are what we predicted. Nice to have it working and to have the flexibility and the advice of Dr. Temple. A learning experience.

Sara: I knew there was a particular answer we were going for. I knew that there were several ways that I could do the research and that no way was going to be the right way. There might have been a more effective way to get at the answer. [Dr. Temple] was the expert and knew the most effective way to do the research. I saw him as a respectable scientist and as a mentor. Most of the things we're finding out have probably already been discovered but as far as we know, it's real.

Greg: Dr. Temple seemed to indicate when we weren't going in the right direction or that there was something we needed to change.

Ralph: Dr. Temple has done major research on this organism and knows more than I will ever know about it. With [his] continued help we have moved out of the conceptualizing and into the doing.

Alice: We were kind of apprenticing with him. He was able to direct us throughout the experiment. Yet he really withheld information from us. He didn't tell us anything. He knew the right questions to ask. He knew where to direct the questions. [Eddie asks "Do you think it's fair to say he didn't tell you anything?"] Well, no. He would direct us. He would provide a question. If we were on the complete wrong track, he would steer us the right way. He did provide us information. He really forced us to do it on our own.

Richard: Well it wasn't that he was questioning that you were or weren't doing the best you could do. It was that he was trying to get you to think and not give you the answer. You know, it took maybe two or three times to kind of go through the drill. But again, it wouldn't be our experiment if he told us "Do it this way with these steps and this sample size." It wouldn't be ours anymore.

Frustration. As the students began to get more deeply involved in their inquiries with the C-Fern™ they began to experience severe frustration. The methods, conclusions and plans they had did not parallel those of Dr. Temple (see above). All of the students agreed that the word "frustrated" was accurate in describing their emotional responses to these early exchanges with Dr. Temple.

> Susan: At first it was so troubling. He would come up with a question to answer your question. It was a very unsettling feeling. You were being asked a lot of questions that show your lack of knowledge. We really got annoyed with Dr. Temple because a lot of times he seemed to give more questions than answers.
>
> Ralph: The first few weeks with Dr. Temple, we were offered no suggestions. He allowed us to make mistakes.
>
> Morgan: I would tell [a new student] that this is not like any other science or biology class they have ever had. You will get very frustrated at some of the questions that Dr. Temple will give you and you will get very frustrated at the answers that he gives you.
>
> Greg: It's frustrating for everyone at the beginning. The fact that we weren't able to determine sample size, number of treatments, etc. in our experiments became apparent.
>
> Veronica: It's different, very different. You're not given anything basically you have to fend for yourself /// But you get to learn what science is truly about. You don't get answers to your questions, you get questions to your questions. [Students] are going to get frustrated at times, so frustrated. [Eddie asks "What kind of frustrations?"] Just experiments, just thinking them up. We are so used to, around here, of having the cookbook recipe of an experiment and ///

> not having to actually think about things on your own and that's frustrating. I mean I love Dr. Temple to death but I was so mad. I was so mad. It was just question after question. "You found that out but how can you prove it?"
>
> Richard: Phillip, Greg and I were drawing blanks as to what our control should be.
>
> Basma: Just when we thought we were almost finished and had discovered what we thought we needed to discover, Dr. Temple always comes up with another question that makes us look back and doubt some of our findings as well as form new experiments.
>
> Veronica: We thought as of last week that we had an experiment started but soon found out we didn't. This made me very frustrated. Dr. Temple told us that we didn't have a control for our experiment so actually we didn't have an experiment; just observations of our unknown. My partner and I were very upset about having to start back at square one. We spent about an hour gathering information to create an experiment. When we finally created one, we told Dr. Temple about it. He thought it would be a good experiment. I felt so much better. I was starting to panic but everything worked out.
>
> Ralph: It was most interesting to reflect with Susan the other evening. She tells me of the frustrations of keeping her group on track looking at just one experiment.
>
> Susan: We had some difficulty with Dr. Temple. I don't mean that he is difficult, but that he is trying to lead us to find the answers ourselves and I don't feel very smart in this situation. I don't think we appear very smart to him either. The thing he does very well is ask a lot of questions.

One of the most interesting series of responses concerning frustration came from Alice. In her concluding interview, she noted that she believed she was too advanced for the course at the beginning but that she felt challenged. Several days into the beginning of the class, Alice complained about the simplistic nature of the course and her laboratory supplies. Ultimately, she realized that her experimental methods lacked controls and that she failed in her first attempt to formulate a sound experiment. The following series of quotations have been extracted from Alice's interviews, from her reflective journal and from videotapes.

> I think I thought that I was [too advanced] going into it. The very first couple of days when we just had the materials and you just set us loose, I was frustrated because I didn't know what to do.
>
> I still get frustrated with the "shabby" experimentation supplies and techniques because at [another university I attended], we were very strict with all our procedures. [Denise wrote to Alice in her reflective journal: Most of the course techniques are going to be geared towards things that you can replicate in middle or high school settings...However it does not mean that this is not "real science"].
>
> Dr. Temple came by to discuss our experiment with us. After a lot of discussion, we realized we had too many variables running, too many questions that we were investigating, and NO controls. I was frustrated to tears, but Dr. Temple was patient and persistent on making me realize why I was so frustrated. And he was determined to help me figure out how to get out of it. I explained that I had spent years working on research under professors and graduate students, and it was so hard to really truly go back to basics. Finally I realized I would have to start at ground zero. We needed to start over with something definitive to have a controlled experiment. When I started thinking in those terms, I had more questions on how to make a control. Dr Temple listened to me argue until I figured out an experiment with a control. He steered me away from over-analyzing it too much, but to ask simple questions, trying to eliminate as many variables as possible. The next class, we listened to other groups' observations. However it seemed that they were just as bewildered when Dr. Temple asked them what their controls were.

[Eddie asks what her biggest frustration has been with her first experiments]. We had to go back to the very beginning. That was really hard and it was hard to think of controls. In all science classes that we've had, they've always been given to us so it was stretching our brain in a different way.

[Eddie asks if the work she has done with C-Fern™ is real science or pretend science]. Definitely real.

Felt a sense of accomplishment and progression. All of the students indicated a feeling of pride, accomplishment and progress as the first of their inquiry experiments passed. The students' affect changed from one of uncertainty and frustration to one of confidence. Some representative comments made by the participants are listed below.

Susan: It gets easier. A lot of it had to do with confidence.

Alice: Science gets fun after you get started! We were all kind of frustrated and then we felt like we were succeeding.

Veronica: My partner and I finally came up with the experiment for our fern. This was very exciting because it's finally coming together.

Richard: I made an observation that Dr. Temple said no one had made in all the years that he has taught the course. He stated that it was a very good observation.

Basma: [I feel proudest of] actually starting to think like a scientist. Before, we were just coming up with a whole bunch of questions and didn't know how to start. The questions make much more sense than when you first started.

Susan: I feel like it's making me think more like a real scientist.

Saw collaboration as important. Several of the participants mentioned that they believed collaboration during their class activities was important.

They also viewed it as helpful and enjoyable. Only one participant, Phillip, said that collaboration was sometimes a problem "if group members aren't pulling their weight." Other comments regarding collaboration are listed below.

> Sara: We've got a lot of supporting evidence from Richard's group. They are kind of looking at the same thing we are.
>
> Greg: Initially I felt that we probably [were not] communicating enough between groups. [Now] I am beginning to see that the collaboration between our groups is becoming vital. When viewed independently, some of our undertakings don't make much sense. While integrating them together...should yield some useable results. I believe that combined with the results of the experiments of the other groups in the class, we can make some inferences and move in some new directions.
>
> Ralph: Sharing of responsibilities continues to work well.
>
> Richard: I enjoyed listening to others and what they learned, what mistakes they made, how they improved their experiments and what was to be done. Everyone seems to be willing to share information in what his or her group is doing which is nice.
>
> Phillip: It will be interesting to see if all of the groups continue to share their information as freely as they have been. The fact that our class shares information so readily relates to something that I have never really thought of until now, personal recognition. For the sake of our class, I feel we all share the opinion that "we're all in it together."
>
> Alice: It was a good bonding experience for the group we had. It was a good example of co-teaching. It was a good example of scientists doing the same thing.
>
> Greg: There was a lot of collaboration and interaction. It was a good thing. There were some negatives but on the whole it was good. It helped with comfort levels and coming up with new ideas.

Found their experiments to be relevant and interesting. Throughout most of the duration of the course, participants seemed to be very interested in the work they were doing. Further, they encountered several instances in which the research they were doing was arguably needed.

One of the first experiences with relevance came from an experiment with C-Fern™ that was completed by Sara, Susan and Basma (see above). This study involved freezing the fern spores and studying their germination. The following exchange, which occurred during the group's presentation of their results to the class, speaks to the issue of the relevance of their research.

> Basma: We wanted to see if spores germinate quickly when they've frozen. The reason we did this /// We noticed that when we were sterilizing the spores that it took a little bit longer to grow. So we were wondering what was a good experiment that we could do that would actually either have them stop growing or grow at a slower rate. So, we read through this book and a scientist said that climate can change the amount of spore growth. So /// we thought about freezing the spores.
>
> Sara: This could kind of relate to real life /// Maybe there's a cold spell, since they're native to tropical areas.
>
> Dr. Temple: I can relate this to a real incident that happened about a week ago. I wish I'd known this then. Somebody that ordered C-Fern spores from [the supplier] had them shipped to South Dakota. They called /// They said "Something's wrong with my culture. Nothing's happening. What's wrong?"
>
> Susan: Did it sit outside too long?
>
> Dr. Temple: Well /// that's one of the possibilities. But we didn't know and I had not done any kind of long-term freezing test.

A few other instances when the participants found relevance and interest in their research are worthy of note. In the transcript appearing in Table 5, for example, Alice reported the need to do relevant research by stating that "I really want it to be something that really is out there, that people really do use" (line three). The study on acid rain completed by Susan, Greg and Phillip shows similar relevance. For example, Dr. Taylor and Eddie conversed with the students about how their study related to the major problems of acid rain and reforestation in the state and surrounding regions (lines 14 - 26). During their presentation, these students discussed the local historical effects of acid rain. Further, from another group, Sara mentioned that her group's research is "kind of practical" in terms of growing seasons for plants in temperate climates (see Table 5, line 32). Finally, Ralph and Morgan noted that their study of salt tolerance in grasses may be important in areas prone to hurricane. Dr. Taylor noted the potential economic applications of this study (lines 34 - 37). During the concluding interview, Susan also spoke in more general terms to the issue of relevance and interest.

> Susan: We were really involved in everybody's experiments. I mean we were curious. We were all, everybody, going around and checking on each other's experiments.

Believed no actual or right answers were known relating to the second round of inquiry. All students agreed that the research questions they selected for their second inquiries probably had not been directly answered by other scientists in the past. However, the students offered little in the way of elaboration about this in their concluding interviews. They also viewed their research questions as mostly novel. Some students found confusion and contradiction in the published literature relating to their general topic of inquiry. One comment from Ralph's reflective journal speaks to the issue of doing research with no predetermined answers.

> Ralph: [Morgan and I were] able to chat and were happy to hear Dr. Temple approved of our work. The other questions he felt necessary for the basic inquiry. We are now heading down another path entirely and answering questions he did not have the answers for - or so he said.

<u>Found that science often requires creativity.</u> All participants verified this affective experience in the concluding interview. Several examples involving the need for creativity occurred as the students found they had to invent or modify methods to carry out their research plans. One of the most interesting examples is described below.

During the experiment that Sara, Richard and Basma completed on the effect of temperature on germination and growth of plants, the students ran into a couple of stumbling blocks. The first involved controlling extraneous variables while focusing on the experimental variable of temperature. Referring to Table 5, (lines 32 - 33), note that Sara discussed her group's dilemma. She noted that their original plan was to place a group of plants inside a refrigerator in order to expose them to cold temperature. However, she stated that "the light is going to go off when you shut the door. So that's our question." Dr. Taylor made several suggestions to the group and notes "You kind of have to invent all these ways of doing experiments..." The group continued to struggle to come up with a method of utilizing cold temperature, without blocking light exposure, in their experiment. The following excerpts are from a group discussion following the whole-class discussion appearing in Table 5.

> Sara: We still have to get through this hot verses cold thing.
>
> Richard: The sliding glass doors or windows /// Dr. Taylor said /// What do you think about that?
>
> Basma: Well the temperature>>>
>
> Richard & Basma: It's not constant outside.
>
> Basma: We have to have control.
>
> Eddie: Could you get one of those battery operated lamps like you see in the stores and on TV? You know /// they use them in closets or something. If you're worried about electricity /// using an extension cord or something?
>
> Richard: We could use rechargeable batteries /// I guess. I think I have some or can get them.
>
> Basma: And put it in the refrigerator?
>
> Sara: A flashlight?

Initially, these students opted for a battery operated light placed inside a refrigerator to facilitate their experiment. In her reflective journal, Sara described this initial attempt.

> Sara: Our first challenge was to figure out how to get a light to remain on in the refrigerator. We wanted light to be constant in order to eliminate it as a variable. We decided to use a battery operated touch light. The controls are being kept under the [fluorescent] light in the classroom. It doesn't give off any heat but it will insure that the specimens are kept under constant light.

It is at this point that the students also began to have a problem with maintaining their sunflowers for the experiment. In her concluding interview, Sara discussed this second problem that required creativity on the part of her group.

> Sara: We had to rig this. Sunflowers get so tall so fast. We had to keep redesigning our layout to accommodate for that. So creativity was definitely a part of designing that experiment. We had to keep constantly changing it.

Basma, in her reflective journal, reported to Denise that the battery operated lamp they first tried to use failed to work. She suspected the moisture in the refrigerator was the cause. Richard wrote to Denise about the "kinks" they had to work out. He noted that the "battery bulbs shorted out so we didn't even try to use electric." Finally, the group opted to keep their plants in a commercial cooler with a built-in lighting system. In this way, they could keep a constant cold temperature and control for the extraneous variable of light.

Another aspect of creativity is dealing with unexpected results and failures. In other words, how does one adjust their method or hypothesis when confronted with results they do not expect. How does one deal with failure? Meyer and Carlisle (1996) reported that elementary school students tended to abandon experiments that yielded unanticipated results. The participants in the "Just Do It" course sometimes, however, tended to try to work through and assess unexpected outcomes. Comments from Phillip and Susan regarding their study of acid rain are noteworthy.

> Phillip: The fact that the pH 4 plants are doing so well is a bit disturbing. We hypothesized that the pH 4 plants would do the worst of all our samples, but they haven't. But hold the phone. As of the last time our group checked on the plants in our sample and observed them we are starting to see a difference. The pH 4 plants are starting to turn yellow in their leaves, something that isn't happening to any of the other samples. Perhaps the sulfur added to the plants in concentrations that are between pH of 5 and 6 affect the growth of the plants, while the pH reaches to around 4 the growth isn't as affected, but the plants

> will begin to show signs of deterioration, such as yellowing of the leaves. This is just speculation so more in depth study would be needed to be conducted to verify this hypothesis.
>
> Susan: I keep reminding myself that Thomas Edison supposedly discovered about 9000 ways how not to make a light bulb. These experiments are telling us something, even if we haven't figured it out. I think I learned a whole lot more about acid rain by doing an experiment that kind of failed to show what we wanted it to show, or expected it to show, and trying to understand more about that, than if I decided, "I think I'll read about acid rain today." We would probably design [our acid rain study] a little differently if we were to do it again because there were a lot of other things we found that come into play. So we learned a lot from that experiment.

The above section of this research report has dealt with evidence related to the first research question posed in Figure 11: What are the experiences of students who learn science through inquiry? Experiences fell into two broad categories. The first category reported was pedagogical experiences, the second reported was affective experiences. Figures 12, 13, and 16 present a summary of these experiences relating to inquiry. In the next section, results relating to the participants' experiences with authentic assessment techniques will be reported.

Question Two: What Are the Experiences of Students Who Are Assessed by Authentic Techniques?

Figure 19 shows an overview of the results related to this research question. The experiences of the research participants, while being assessed by authentic techniques, fell broadly into two categories. The first category includes pedagogical experiences related to assessment. The second category includes affective experiences related to assessment.

Question 2: What are the experiences of students who are assessed by authentic techniques?

I. Pedagogical Experiences Relating to Authentic Assessment
  A. Reflective Journal
  B. Journal Club Presentations
  C. Inquiry Lesson and Presentation
  D. Laboratory Inscription Notebook
  E. Participating in Interviews
  F. Defending Conclusions and Methods

II. Affective Experiences Relating to Authentic Assessment
  A. General Reaction to the Assessments
  B. Reaction to the Informal Assessment of Defending Methods & Conclusions
  C. General Reactions to the Laboratory Inscription Notebook

Figure 19: Overview of Results Relating to Question 2

Pedagogical Experiences Relating to Authentic Assessment

Figure 20 presents a summary of the various pedagogical experiences, relating to authentic assessment, had by the research participants during their course enrollment. Details on each pedagogical experience are provided below.

Reflective journal. All students were required to maintain and make regular entries in a reflective journal throughout the course. The reflective journal, along with regular participation accounted for 15% of the students' total course grade. The participants regularly shared computerized entries in their journals with Denise, one of the teacher assistants in the "Just Do It" course. In turn, Denise made comments to the students and/or addressed their concerns. It is of importance to note that neither of the primary course instructors (Dr. Temple and Dr. Taylor) nor Eddie had access to the student's reflective journals during the course. Therefore, the students could feel more at ease with making entries in their journals without fear that their grade in the course would be adversely effected. Students were encouraged to use the following list of questions to help facilitate their writing.

*How do you feel about the course so far?
*What frustrations, if any, are you experiencing?
*How are groups forming, if any?
*How much do you understand about what you are supposed to be doing?
*Is this course similar/dissimilar to previous science courses/experiences?
*What is the nature of scientific thinking, and specifically, yours?
*How is your own scientific thinking developing?
*What is scientific thinking?
*What is the nature of science?

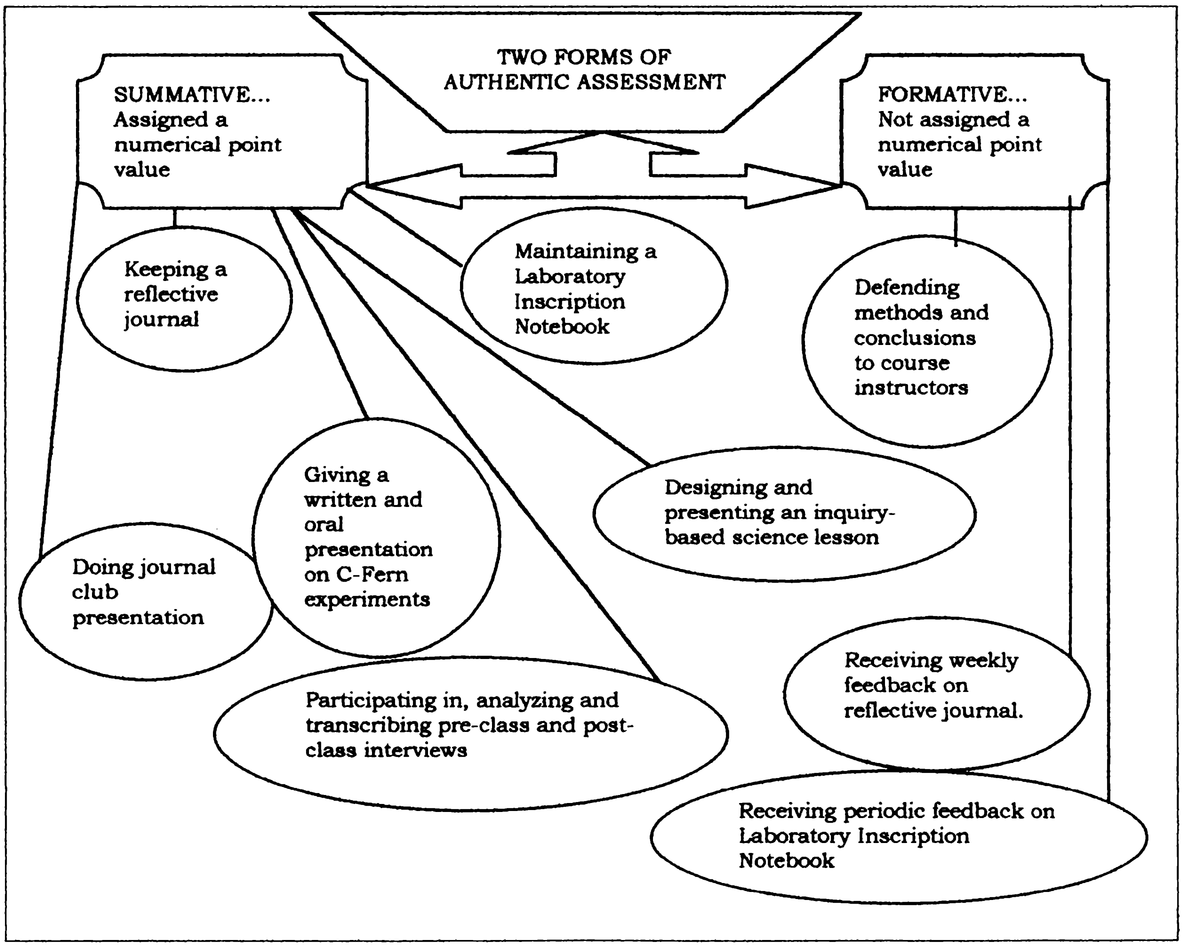


Figure 20: Summary of Pedagogical Experiences With Authentic Assessment

Students wrote on the above topics, and on others. Excerpts from the participants' reflective journals appear throughout this research report. During the post class interview, four students specifically mentioned the reflective journals, without prompting, when asked about evaluation in the course.

> Sara: I think the /// um reflective journals was a great idea because it let us get things off our chest and I know I felt really comfortable talking to Denise and presenting her with some frustrations or problems that I was going through throughout the semester. And she gave me some pretty good advice or said "you know students say that every year." You know, knowing that I'm not the only one that's going through those kinds of problems ///.
>
> Greg: The reflective journal you have to keep up weekly, is kind of a pain. Especially if you have four other classes with reflective journals.
>
> Basma: I liked the journal because it really helped me reflect. I would not have thought of doing journals on my own and then I would not have been able to go back and read what I did in this course if I did not have it.
>
> Morgan: The weekly reflections help you keep [your work] on your mind and think about it a little.

Journal club presentation. The journal club presentations, as well as the students' reflective journal responses to the experience were described in the previous section. The assignment, essentially, was to locate and critique a scientific paper of interest. Students discussed their papers orally during class. The presentation accounted for 20% of the total course grade. They were graded according to the rubric shown in Figure 21. As with the reflective journal, some students (two in this instance) offered specific comments without prompting by the author on this assessment activity in their post class interviews.

Components	POINTS 4 3	2	1
Journal Article Selection	**Appropriate selection** -I)Biological Science Periodical (Call number from LC–Qs), ii)Current (<4 years old), iii) Appropriate length, iv) Appropriate complexity	**Partially Appropriate selection** - two/one of four subcriteria	**Inappropriate selection** – four subcriteria absent
Overall Verbal Presentation	**Complete description of selection –** Overview of article including background for understanding research, specific question(s) or hypotheses posed, purpose of research	**Partially complete description of selection –** attempt to describe the background and purpose but insufficient understanding and explanation	**Absence of description of selection** - Lack of understanding and description of general background information
Overall Visual Presentation	**Appropriate visual description of experimental design and data** - Handout(s) and/or overhead(s) that fully depict experimental design and illustrate the data collected and its analysis.	**Partially appropriate visual description of experimental design and data –** e.g. too much data, too little data, information not labeled appropriately, content not understandable	**Completely inappropriate visual description of experimental design and data** - Absence of suitable handout(s) and/or overhead(s)
Explanation of Article's Experimental Design, Methods and Data	**Complete explanation of experimental design and methods** - including I) identification of control(s), ii) identification of treatment(s), iii) sample size(s), iv) analytical and statistical tests,	**Partial explanation of experimental design and methods –** two/one of four subcriteria	**Insufficient explanation of experimental design and methods** - Failure to identify control(s), treatment(s), sample size(s), analytical and statistical tests
Analysis of Article's Experimental Design and Data	**Appropriate analysis of experimental design and data** – Commentary by student on I) strengths and ii) weaknesses of methods and experimental design, iii) discussion of problem(s) with design, iv) ameliorating factors	**Partially Appropriate analysis of experimental design and data** – two/one of four subcriteria	**Absence of analysis of experimental design and data** – No discussion of strengths and weaknesses of methods and experimental design, discussion of problem(s) with design, ameliorating factors, conclusion.

Figure 21: Rubric For Journal Club Presentation

> Basma: I also liked the journal club presentation too because I actually got to go out and find a journal article on my own.

> Sara: The journal club presentation I think was /// was a great idea because we got to see exactly what a /// what a real scientific paper is /// should look like. And what research should look like and what it should /// to give us a good /// indication of what we should have learned from the class.

Written and oral research presentation. As a group, students were required to present a formal oral presentation of the research completed during the inquiry with C-Fern™. A short summary of their research questions and experiments is shown in the previous section. Each student was expected to contribute to the overall presentation. Further, each student was required to complete a formal, written research report about at least one of his or her experiments. This assessment contributed 25% of the total course grade. The rubric used to evaluate this assessment is shown in Figure 22. An interesting aside is the fact that Dr. Temple allowed students to continue revising their written papers until they were satisfied with the grade they received. It is of note that in actual scientific practice, professional papers are often peer reviewed and returned for correction and/or clarification prior to their publication. Further, scientists often present research findings to their peers at seminars and symposiums. In this sense, then, the written research paper and oral research presentation were particularly authentic.

The students' first written drafts of their research reports followed a typical scientific research report format in that the students used headings such as Introduction, Materials and Methods, Results, etc. The students included a variety of inscriptions to summarize and/or clarify their results and

COMPONENTS OF REPORT	POINTS 4 3	2	1
1. INTRODUCTION – justification and background	Clearly presents the basis and rationale of the experiment, along with any background material that is appropriate.	Only partially presents the basis and rationale of the experiment.	Does not present the basis and rationale of the experiment.
2. MATERIALS AND METHODS – experimental design	All variables are properly identified and dealt with. The experimental design is adequate. This includes: data to be collected, controls, techniques utilized, an adequate number of replicates.	Only some of the variables and design issues are correctly identified and dealt with.	None of the variables and design issues are properly identified and dealt with.
3.RESULTS – presentation of data	Complete and adequate. Tabular and/or graphic representation of data where appropriate.	Only partially adequate; graphic and/or tabular data are not clearly represented. Some components are omitted or improperly identified and/or presented.	Description of results is totally inadequate.
4. DISCUSSION – analysis and interpretation of outcomes	Appropriate interpretation and discussion of the outcomes of the experiment. Possible implications/further experiments are proposed.	An adequate interpretation of the data is presented, but it is not related to possible implications or additional experiments are not suggested....OR vice versa.	The data and implications are not adequately discussed.
5. ORAL - Overall Verbal and Visual Presentation	Excellent use of visuals and clear, well-rehearsed and enthusiastic presentation.	Presentation adequate, but considerable room for improvement of verbal and/or visual portions.	Unorganized verbal presentation with ineffective use of visuals.
5. WRITTEN – Grammar and language use.	Grammar/language use is very adequate.	Grammar/language use is inconsistent or somewhat inadequate.	Grammar/language use is generally poor.

Figure 22: Rubric For Evaluating Written & Oral C-Fern Reports

methods. These initial drafts are probably best described as interesting and promising, but unpolished. Some students mixed methods and results in the wrong sections. Others went into meticulous detail on trivial aspects of their procedures while neglecting the more important ones. Some inscriptions were not well labeled or explained in the text. Some papers were far too lengthy for comfortable and efficient reading, others were far too terse for clarity. Most of the students took advantage of the opportunity to continue to revise and resubmit their papers. Comments regarding the written and oral research report on the inquiry with C-Fern™ are included below. These comments were extracted from interviews, reflective journal entries and videotape. Some examples of inscriptions from the research papers and oral presentations, as well as excerpts regarding methods and quality of the studies, will be presented in a later section of this chapter.

> Basma: Well Dr. Temple really got me on the written but it was actually good. He taught me a lot because there were a lot of things that I was writing into my presentation or to my research paper that I didn't need and it was making it so long that probably nobody would want to read it. So he helped me on learning how to write a scientific paper.
>
> Morgan: I would make...the research paper, oral and written [count for a higher percentage of the course grade]. Because that took a lot more time.
>
> Susan: I liked the fact that Dr. Temple checked our papers and allowed us to improve them. Because I actually thought I had a pretty good first draft and you know what I ended up with was not what I started out with at all, totally different papers. But I liked that aspect too, that opportunity to improve it.
>
> Basma: I really liked the presentation because we got to learn a lot more about the C-Fern that we did not

> learn from our own experimentation, which could lead us to other new experiments to form.
>
> Morgan: We separated our [oral] report up into two sections. I really liked the way that Ralph's information and mine flowed together. The thing that made us think we did a good job was that Dr. Temple did not ask us a single question.
>
> Richard: I submitted my 3rd draft to Dr. Temple and am praying for less red ink on the return. I have written the first two knowing that the reader is an expert so the language was very vague. Dr. Temple said it should be written for the uninformed so I went into great detail.

<u>Inquiry lesson and presentation.</u> All participants were required to present an inquiry-based lesson, derived from their inquiries with other organisms (see above) to the other members of the class. Also, the students were required to utilize the 5 E pedagogical model (Trowbridge & Bybee, 1995). The inquiry lesson accounted for 25% of the course grade. It was graded according to a rubric similar to Figure 22 but the emphasis was on the 5 E Model. Further, there was an element of peer evaluation, along with evaluation by the course instructors, in this assessment. Some participants were given copies of the rubric to complete during the presentation of lessons by others. Summaries of the students' inquiries and lessons are described in the previous section. Only Morgan and Susan had things to specific say about the inquiry lesson and presentation in their reflective journals and post class interviews.

> Morgan: We discussed the teaching method of using the five E's. The main point that I got from the discussion is that the method is much like this class. The teacher works more as a facilitator than a direct instructor.
>
> Susan: My personal opinion, I would rather instead of feeling like we had to get through it that everybody got

the time that they needed based on their presentation.

> Morgan: The inquiry experiment and lesson probably should not be one fourth the total grade, in comparison to the amount of work that was put into everything else.

Laboratory inscription notebook. The research participants were required to maintain a laboratory inscription notebook throughout the duration of the course. In the notebook, they were asked to record inscriptions relating to their inquiry activities and observations in the course. The rubric used to evaluate the notebook was presented to students on the first day of class, along with explicit instruction about the uses of inscriptions by scientists. The rubric is shown in Figure 9. The laboratory inscription notebook accounted for ten percent of the total course grade. Further, students were given periodic feedback about their notebooks prior to their summative grading.

The notion of scientific inscriptions is central to the theoretical underpinnings of this research report (see Chapter Two). A wealth of data relating to inscriptions was collected during the course of this study. Also, much of the data for this study is derived from students' experiences with inscriptions and the actual inscriptions they made during their enrollment in the "Just Do It" course. Therefore, results relating to the participants' scientific inscriptions are varied and are presented in various ways. A separate subsection dealing exclusively with examples, and uses, of inscriptions by the students is presented below. Further the overall usefulness of scientific inscriptions in helping students to design and carry out successful science experiments over time is considered in a separate section, also shown below.

Finally, affective experiences relating to inscriptions as assessment tools are also presented within a separate subsection, below. In the present subsection, a few comments from the participants relating to inscriptions in a more general way are offered. These comments were extracted from interviews, reflective journals, videotapes and class discussions. Presentation of these comments allows the participants to discuss their experiences in their own words.

> Sara: Learning how to make accurate inscriptions is really important in learning how to practice science.
>
> Greg: The inscription notebook; that's all of your work for /// kept every class. That adds some validity to it. I think it could be weighted more. Put more emphasis on putting everything in your notebook. And get two of them 'cause you'll run out of paper.
>
> Morgan: I loved doing it. I seem to forget what I did yesterday if I didn't write it down, and it especially helped in doing the reflective journals and keeping the lab notebook is good reference material. I am sure I will go back to it whenever I am teaching my class.
>
> Richard: I loved taking /// making inscriptions /// drawing. And I've been told in the past to look into biological illustration. I don't think that portion should change. That may even /// I think it should count more actually because it is a daily thing as opposed to [other things we did]. Something that you put your work into every single day should have, I think, should have more bearing on your grade than just one presentation.

<u>Participation in, and transcription of, pre- and post-class interviews.</u> All students were awarded points counting toward five percent of their total course grade for participating in individual pre- and post-class interviews (see Chapter Three) with the author. Further, the participants were asked to transcribe

these interviews and present a brief written comparison between the two interviews.

Defending conclusions and methods. Throughout the course, but particularly during their inquiries with the C-Fern™ (see above), the participants were regularly required to defend their conclusions and methods to the course instructors. Almost every time one or more participants made statements regarding a possible conclusion with their experiments, they were asked specific questions about their methods, sample size, control or other aspects of their work. It should be noted that the author considers this to be a form of authentic assessment because professional scientists are regularly called upon to do the same things. However, it is also of important note that no numerical or letter grades were assigned to the participants based on their responses to questions they were asked.

Numerous examples of exchanges between the students and course instructors (as well as teacher assistants) occurred throughout the course. Returning to Table 4, for example, take note of the fact that Dr. Temple asked the several evidence-demanding questions of students who were presenting possible findings to him in an informal setting. In line six he asked "How do you prove that?" to students who claim they have evidence for two gametophytic growth forms in the C-Fern™. In the exchanges involving Dr. Temple, Greg, Richard and Alice (lines 16 - 30), Dr. Temple continued to demand details about sample size, treatment and adequacy of evidence to support the students' results. The same pattern is evident in Table 6. Note that Dr. Temple asked Susan "Can you show that, can you prove that?" (line six) when she made a statement regarding the life cycle of the plant. Another example may be found in lines 63 - 64. Notice that Greg and Richard believed they had solved a mystery regarding the beginning of the sporophyte stage of the C-Fern™ life cycle. Their observation, in this case, was ultimately correct. However, notice that Dr. Temple said in line 64, "That could be a hypothesis...Can you demonstrate that?" Other examples of the tendency of the instructors and teacher assistants to ask students to present specific evidence to support their claims and conclusions are found throughout Tables 4, 5 and 6. Further, as previously noted, this demand for defending conclusions became a regular pattern early in the course.

Affective Experiences Relating to Authentic Assessment

In the previous subsection, a few affective or emotional responses to some of the pedagogical experiences with authentic assessment were presented. These were listed because they were so specific and focused toward the pedagogical experiences with authentic assessment. The goal of this subsection is to provide a more generalized account of the participants' shared affective experiences with authentic assessment. Figure 23 presents a summary of the various affective experiences, relating to authentic assessment, had by the research participants during their course enrollment. Details on each affective experience are provided below.

General reaction to the assessments used in the "Just Do It" course. During the concluding interview, all of the students reacted very favorably to the general assessment format used in the "Just Do It" course. Further, many students made positive comments throughout the course in other formats as

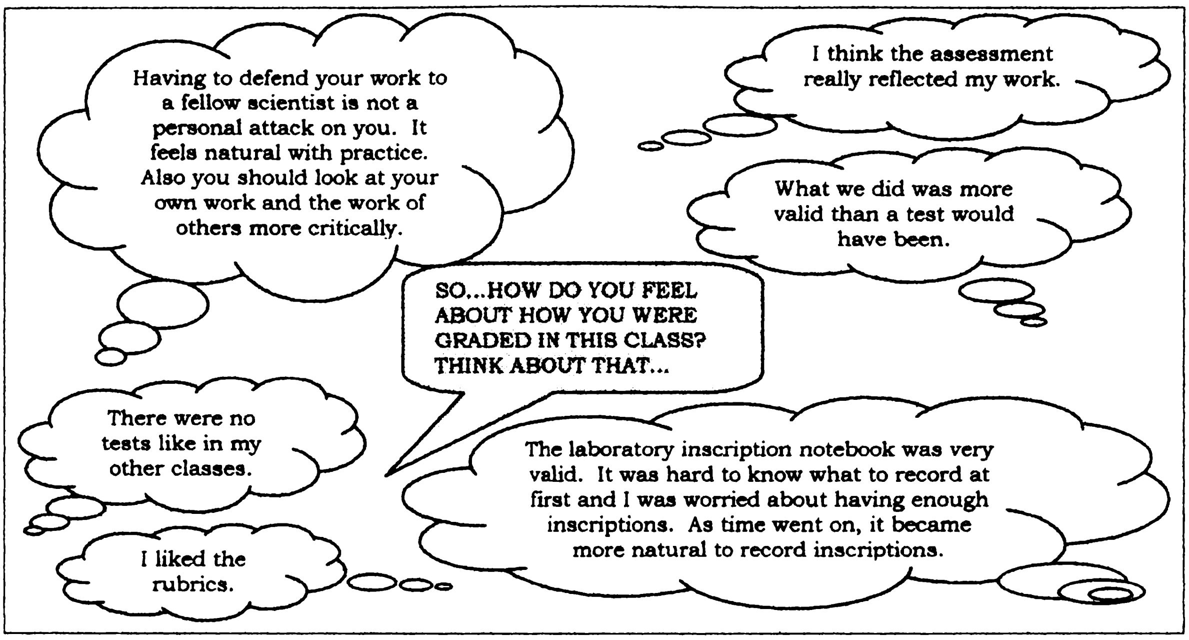


Figure 23: Summary of Affective Experiences Relating to Authentic Assessment

well. Common themes brought out by the participants, and confirmed during the concluding interviews, include the following.

1. Noticed an absence of traditional testing methods, like those seen in other classes. All students confirmed this theme during the concluding interview. Two interesting statements offering elaboration are listed below.

> Sara: Well, I want to make an A but it's not a day-to-day thing with me. Like every time I go into my geology lecture I'm worried about what grade did I get on that quiz. You know it's not as much about the material.

> Veronica: I think it's great. I like it /// because there is so much different things. A lot of it, not like in other classes you have three to four major exams and that's it.

2. Felt the methods used were more real or valid than a traditional test would have been. All students confirmed this theme during the concluding

interview. A powerful testimony, delivered by Morgan during a class discussion, is presented below.

> Morgan: I don't know if it's just me but in traditional schooling where so much emphasis is placed on your grades, I make great grades but I didn't learn squat. Um /// mine mostly was memorization. I'd do my studying, take the test and then [Morgan motions with his hands] it's gone. I didn't really learn much. But I find even in college now, in classes where it's more designed around the grade that you get instead of participation, or what-not, it's still mostly memorization. But in classes where you really have to be involved and just dig down to your ankles in it, you really learn more that way. That's how I feel. But when it is just "You've got to get a 90 to make an A." I'll memorize my 90 percent worth of my material /// and just memorize it.

3. Believed the assessment used in the course reflected their work.

Some students used words like different and unusual to describe the course assessment. Overwhelmingly, though, they reported a satisfaction with the assessment techniques in terms of their validity during the concluding interview. The participants also made various supportive statements throughout the course, some of which are reported below.

> Alice: It was different but I felt it was fair.

> Susan: Well, I guess at first it seemed like everything was going to be rather /// I know this probably will surprise you /// but it did seem a little bit subjective and a little uneasy about the performance and things like that. That was starting out.

> Sara: I think it's pretty accurate. I think the right percentages have been distributed. I think the grading is great. I mean I just loved the class.

> Greg: I think that every teacher from the "old guard" should have to return to [the] university and experience the 2000's version of teacher education. We're not in Kansas anymore.

4. A mostly favorable response to the rubrics used in the course. With the exception of one student, Basma, all participants reacted very favorably to the rubrics used in the course. Basma was not particularly critical of the rubrics but indicated that she was "getting more comfortable with" them.

> Basma: I'm kind of shaky on rubrics. I always end up stressing myself out more. Now I see the point of it and I'm getting more comfortable with it."
>
> Alice: There was a rubric for everything we turned in. That's all I need to feel secure.
>
> Susan: I liked the rubrics. I thought those were really neat and whenever I had an assignment, I just went to the max points and said "What do I need to do to get max points?" Most of these things had nice rubrics that allowed you to say "Ok, as long as I do all this, I can get this grade. And if I don't I'll be eligible for a lesser grade." And I like that because I felt like students probably feel there's a lot of subjectivity in a lot of grading. And if you were able to do this in the classroom a lot for most things, it would take a lot of the mystery out and maybe give them a higher degree of comfort that "Hey this is the grade you've earned."

5. Some concerns about the low reliance on peer evaluation. This was by no means a common theme. However two of the ten participants brought the issue up, when asked in general terms about the course evaluation methods, during the post class interview. The author feels obligated to report this concern because the two participants involved stressed it in such detail. Interestingly enough, the two students who spoke to the issue were in the same collaborative work group during the C-Fern inquiry portion of the class.

> Richard: I think at times the way /// uh /// there could be a problem with the group grade and that sort of thing. If you had three people and only two are doing the work and that sort of thing /// I think that's a problem that happens in any type of group. I think that maybe if there were some way of grading

your peers. In that sense it would be beneficial as far as the overall grade for the group project. The way it was dealt with in some business courses that I took /// we had an evaluation of peers in our group and it kept everybody putting in their share.

Phillip: It's pretty well outlined as to what our grade is and where it comes from. Personally, I think one of the things I see as a drawback would be when you are working in a group setting and members of the group aren't pulling their weight. That definitely becomes a hindrance. You don't want to ruffle any feathers, but that's something I've seen, and that's something you learn about and learn from. But I think the grading system is fine.

Reaction to the informal assessment of defending their methods and conclusions. As noted in the above subsection (see also Figure 20) students were regularly required to present detailed evidence to back up most all claims they made regarding their work. This was particularly true during the inquiry with the C-Fern™. A few of the participants' responses to this experience have already been presented in previous sections. As was noted in the above section dealing with affective responses to inquiry, the emotion of frustration was the common initial theme. During the concluding interview, all the participants agreed that they did not view this demand for evidence as a personal attack. Further they agreed that as time went on they began to feel more confident in, and prepared for, defending their conclusions in this way.

A second interesting aspect of the participants' emotional response to the requirement to defend their methods and conclusions is also worthy of note. All participants agreed, during the concluding interviews, that they believed they could and should (and that they did) evaluate each other's work in this fashion. In other words, the students began to cast the critical eye of a scientist on one another's conclusions, methods and results. In Table 4, for example, one can find two examples of students beginning to critically evaluate the work of their peers. Notice that in line two, Alice made a scientific claim regarding the C-Fern™ life cycle. Susan immediately asked for details, "What was your control and your percentage of results?" (line three). Later in the discussion Sara claimed that the difference observed by Alice was environmental, rather than genetic. Greg asked "How many did you do?" (lines 14 - 17).

<u>General reactions to the laboratory inscription notebook.</u> The laboratory inscription notebook, and inscriptions in general, are considered in several sections and subsections of the current chapter of this research report. In fact, a separate section dealing with examples of inscriptions, is presented below. This subsection will consider only generalized shared affective experiences with the use of the laboratory inscription notebook as an authentic assessment tool. During the concluding interview, all participants agreed that they were not sure what they were supposed to record in their laboratory inscription notebooks at first. All students, with the exception of one, reported feeling an initial sense of pressure to record the minimum numbers of required inscriptions. Finally, they all agreed that maintaining the notebook and making inscriptions began to feel more natural with the passage of time. Supporting comments regarding this are listed below.

> Greg: I think in the beginning some of us were a little unclear about what we were supposed to put in [the lab inscription notebook]. You can put everything in, essentially. I don't think we got that idea. After while we grasped the concept.
>
> Sara: I wanted to record every single thing at first. I kind of cluttered my inscription notebook with

> unnecessary things at first. As the semester went on, I learned how to filter out those unimportant things. Once we got into our experiments, we were way over the minimum numbers. That wasn't even an issue.

> Basma: At first I was just writing down everything I could. Data /// this data. As time went on I started to see which ones are more important and which ones are not as important.

Another theme regarding the laboratory inscription notebook is also worthy of note. Several participants, some without specific promoting about validity, expressed their belief that the laboratory inscription notebook was very reflective of their work throughout the course. The quotations listed below were extracted from post-class and concluding interviews.

> Morgan: You can see they are learning as it is happening. I think that's a better way to do it than giving a test because they can have a bad day and not take a test that well. The lab notebook shows their progression and shows they are learning day by day. And it is their thoughts.

> Greg: And the laboratory inscription notebook, that's all of your work for /// kept for every class. That adds some validity to it plus.

> Sara: I think that the way you actually do your /// inscription notebook and your laboratory notes denotes exactly how you were in actually doing the experiment, which I think is the most important part of this. To be very detailed and very neat and /// you know organize your thoughts well. I think that's the perfect way to reflect that.

> Phillip: I think that is more beneficial that you can see your train of thought and see where you're going with that. [Eddie asks "Do you feel that I was able to get inside your head and see your train of thought?] I would say definitely. At the start it was general information. But, as it went along there would become points where I'd do an experiment and say what's the question /// what's happening, here's my

> hypothesis. I think that helped you know where I was going.

The above section of this research report has dealt with evidence related to the second research question posed in Figure 11: What are the experiences of students who are assessed by authentic techniques? Experiences fell into two broad categories. The first category reported was pedagogical experiences, the second reported was affective experiences. Figures 20 and 23 present a summary of these experiences. In the next section, results relating to examples of scientific inscriptions recorded by the participants will be reported.

<u>Question Three: What Are Some Examples of Scientific Inscriptions Students Record During Their Experiences?</u>

Students were required to maintain a laboratory inscription notebook as part of their course grade in the "Knowing and Teaching Science: Just Do It" course. The students were provided with a rubric (see Figure 9) detailing how their notebooks would be graded. They also received explicit instruction about the various types and uses of inscriptions. More details about how the inscriptions were used in assessment may be found in the above section of this chapter dealing with authentic assessment. Further the overall usefulness of scientific inscriptions in helping students to design and carry out successful science experiments over time is considered in a separate section, shown below. The primary goal of the current section is to list and provide examples of the inscriptions made by the participants during their course enrollment. Figure 24 provides an overview of the results relating to the above, third, research question.

Question 3: What Are Some Examples of Scientific Inscriptions Students Record During Their Experiences?

I. General Examples of Inscriptions
    A. Written Statements
    B. Diagrams
    C. Data Charts and Tables
    D. Mathematical Formulas and Equations
    E. Graphical Inscriptions

II. Examples of Socially Generated or Socially Shared Inscriptions

III. Examples of Transformation Cascades

Figure 24: Overview of Results Relating to Question 3

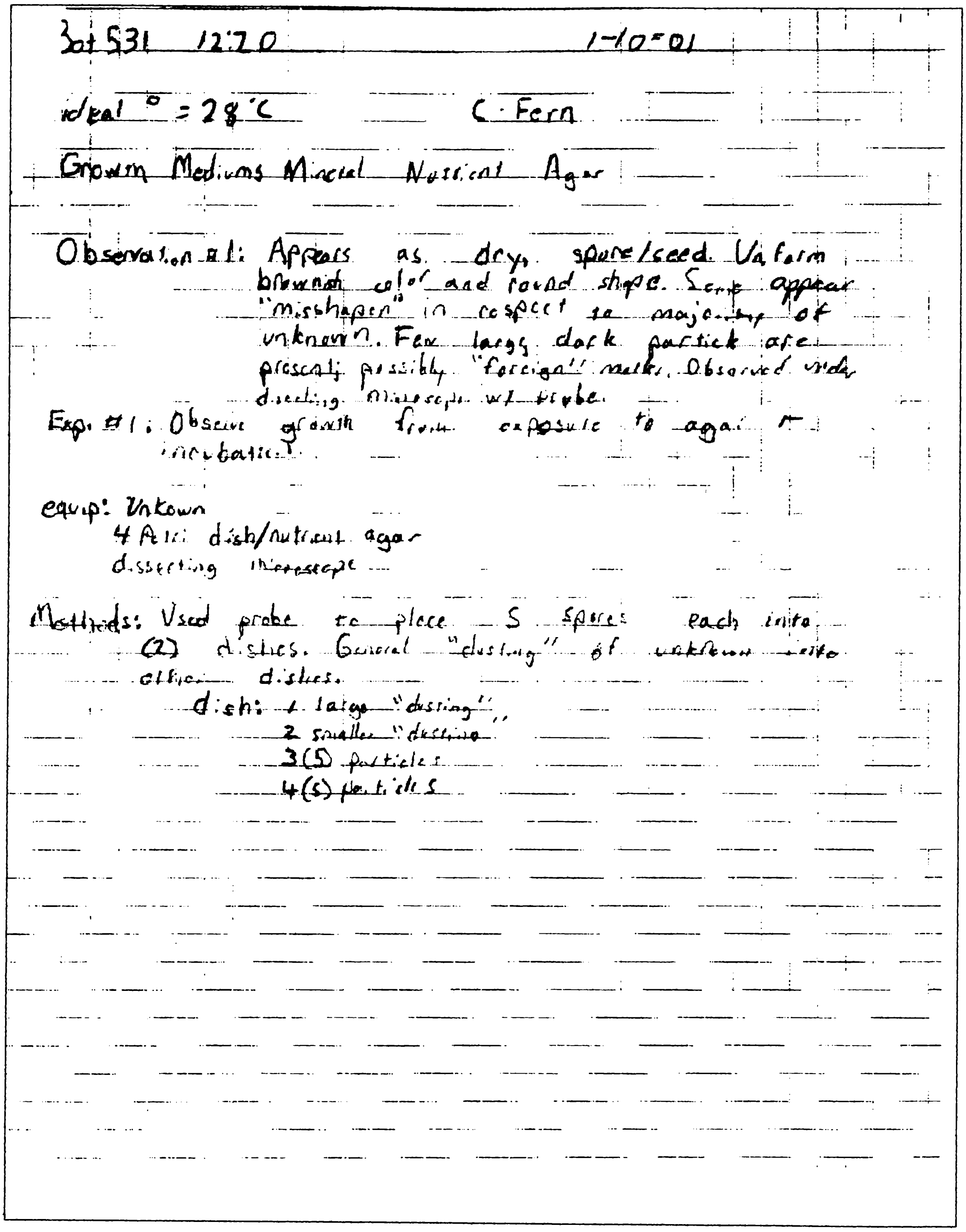
The students enrolled in the "Just Do It" course collectively generated more than 1,500 inscriptions. Inscriptions were mostly recorded in individual laboratory inscription notebooks. However, some students made other inscriptions for their research reports and/or oral presentations. Some of these examples will be presented and discussed below. Further, some inscriptions were made on the classroom chalkboard and/or dry erase board. Most of the later inscriptions, unfortunately, do not survive as artifacts from the course. The remainder of this section will provide discussion, and examples, of representative inscriptions.

General Examples of Inscriptions

While working within the guidelines of the scoring rubric for the laboratory inscription notebook (see Figure 9) students generated a wide variety of inscriptions of various types. Examples included very concrete diagrams and written statements of experimental methods and observations as well as more abstract representations of experimental data, treatments and conclusions. Specific examples, by type, are discussed below.

Written statements. Students made several written statements in their laboratory inscription notebooks about observations, methods, emerging hypotheses and other aspects of their inquiry activities throughout the course. These written statements particularly seemed to dominate entries made in the notebooks early in the course. Figure 25 is a reproduction of Greg's first entry in his laboratory inscription notebook. Notice that the entry is entirely composed of written, descriptive statements. An example from Sara's notebook is shown in Figure 26. In this case, Sara entered statements in her notebook that summarized her work in lab up to the date of the entry (January 31). Numerous other written statements were made by all of the participants. In some cases, the written descriptive statements stand alone (as with the two examples described above). In other cases, written statements were used to clarify and/or accompany other types of inscriptions. An example of this is described below.

Diagrams. Drawings and diagrams were also very common types of entries in the laboratory inscription notebooks, especially early in the participants' inquiry experiences. The students made numerous diagrammatic inscriptions of growth forms of plants, of shapes of spores and seeds, of life cycles of organisms and even of laboratory equipment. A few examples of the many diagrams are provided and discussed below. As noted above, some participants combined diagrams or drawings with written statements in their entries. Phillip combined five diagrams of his observations of growing C-Fern™


Bot 531 12:20 1-10-01

ideal ° = 28°C C. Fern

Growth Medium: Mineral Nutrient Agar

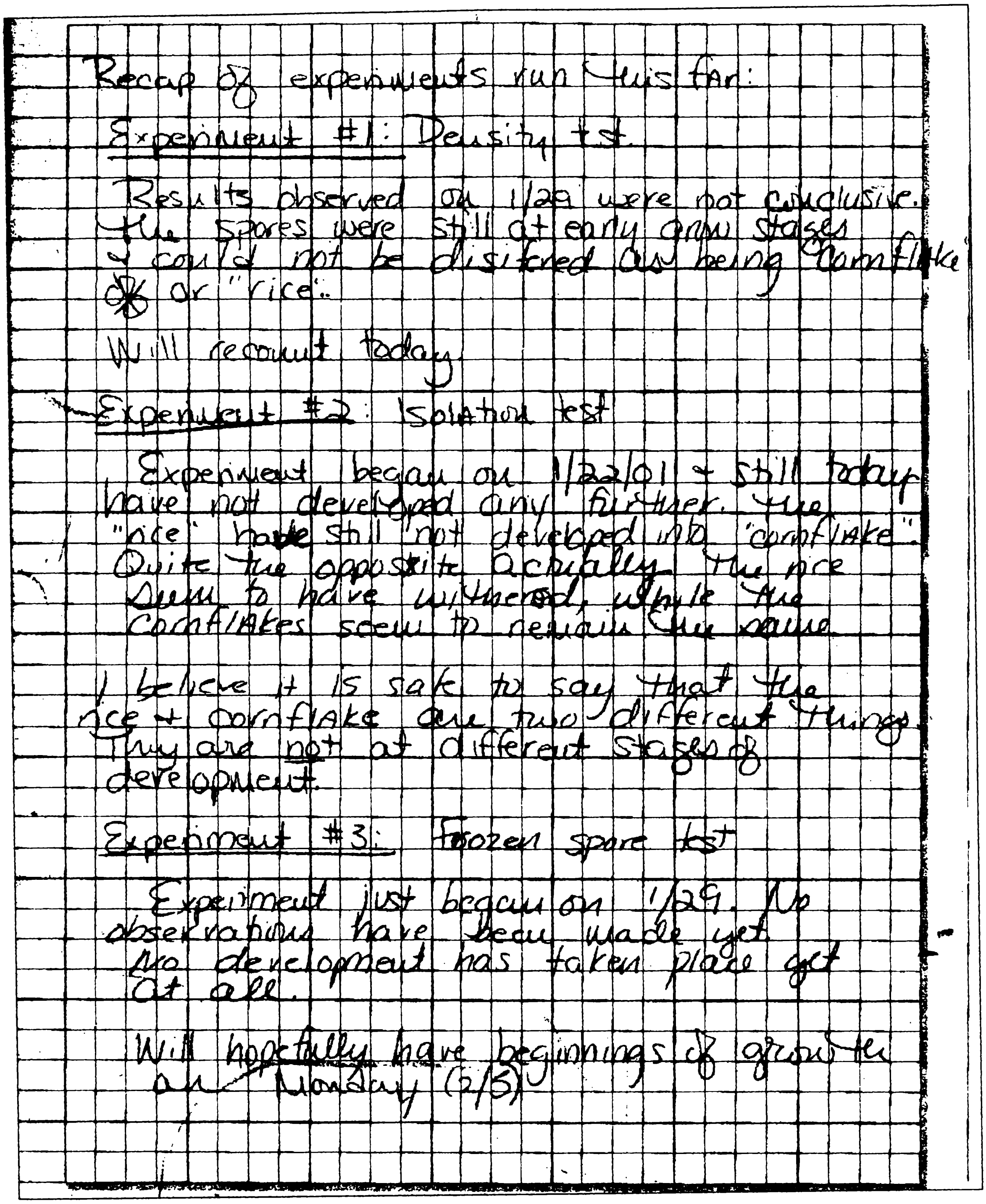
Observation #1: Appears as dry, spore/seed. Uniform brownish color and round shape. Some appear "misshapen" in respect to majority of unknown. Few large dark particle are present; possibly "foreign" matter. Observed under dissecting microscope w/ probe.

Exp. #1: Observe growth from exposure to agar & incubation.

equip: Unkown
4 Petri dish/nutrient agar
dissecting microscope

Methods: Used probe to place 5 spores each into (2) dishes. General "dusting" of unknown into other dishes.
dish: 1 large "dusting"
2 smaller "dusting"
3 (5) particles
4 (5) particles

Figure 25: Greg's First Notebook Entry; Example of Written Statement


Recap of experiments run this far:

Experiment #1: Density test.

Results observed on 1/29 were not conclusive. The spores were still at early grow stages & could not be disifered as being "cornflake" or "rice".

Will recount today.

Experiment #2: Isolation test

Experiment began on 1/22/01 & still today have not developed any further. The "rice" have still not developed into "cornflake". Quite the opposite actually. The rice seem to have withered, while the cornflakes seem to remain the same.

I believe it is safe to say that the rice + cornflake are two different things. They are not at different stages of development.

Experiment #3: Frozen spore test

Experiment just began on 1/29. No observations have been made yet. No development has taken place yet at all.

Will hopefully have beginnings of growth on Monday (2/5)

Figure 26: Example of Written Statements From Sara

spores with a few clarifying written statements concerning his microscopic observations. He further magnified portions of the microscopic field of view and drew those views of the spores as well. These entries are shown in Figure 27.

As the C-Fern™ spores began to germinate during the C-Fern inquiry, all students documented growth patterns of the fern in their laboratory inscription notebooks by way of diagrams. Some of Susan's diagrams relating to this activity appear in Figure 28. These diagrams include views of the two types of gametophytic growth forms of C-Fern™ and a detailed view of male gametes being released from the male gametophyte. Susan and the other students prepared numerous diagrams during other activities in the course as well. Some of these are discussed below.

In another diagrammatic inscription, Susan prepared a tentative diagram of the mealworm life cycle (Figure 29) which was based on her observations of the organism to that point. She wrote down her remaining questions concerning the organism as well. Finally, Basma made some diagrams of germinating sunflower seeds, which are shown in Figure 30. These diagrams related to Basma's inquiry project. They display her observations of the three Petri dishes that contained germinating seeds. Basma labeled roots and the seed coat in her diagrams and added a few other comments. Numerous other types and examples of drawings and diagrams were recorded in the participants' laboratory inscription notebooks.

Data charts and tables. As the students' work progressed with their inquiries, a number of inscriptions featuring charts and tables of data were recorded in the laboratory inscription notebooks. A few of these will be

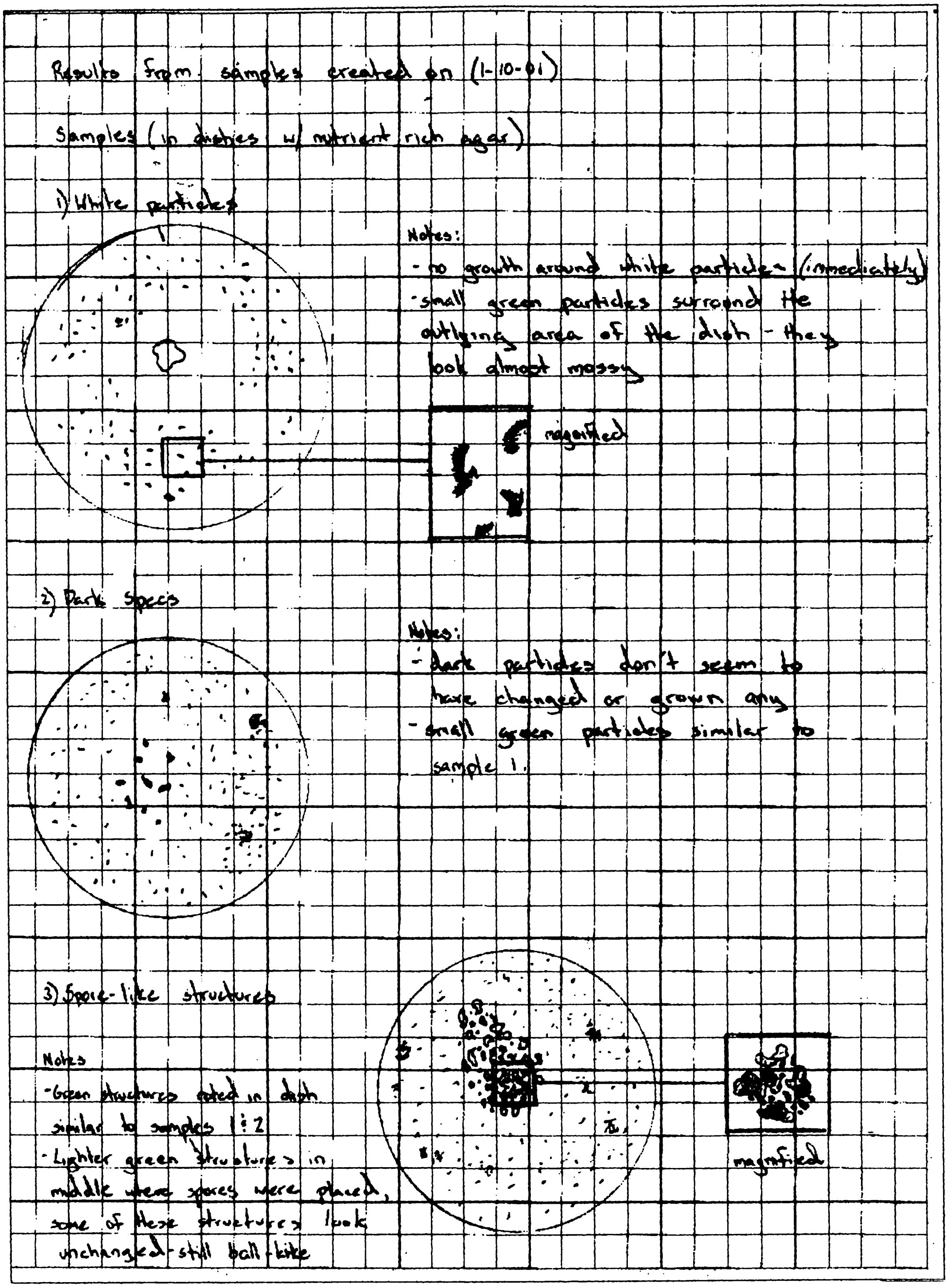


Figure 27: Phillip's Drawings of C-Fern Spores

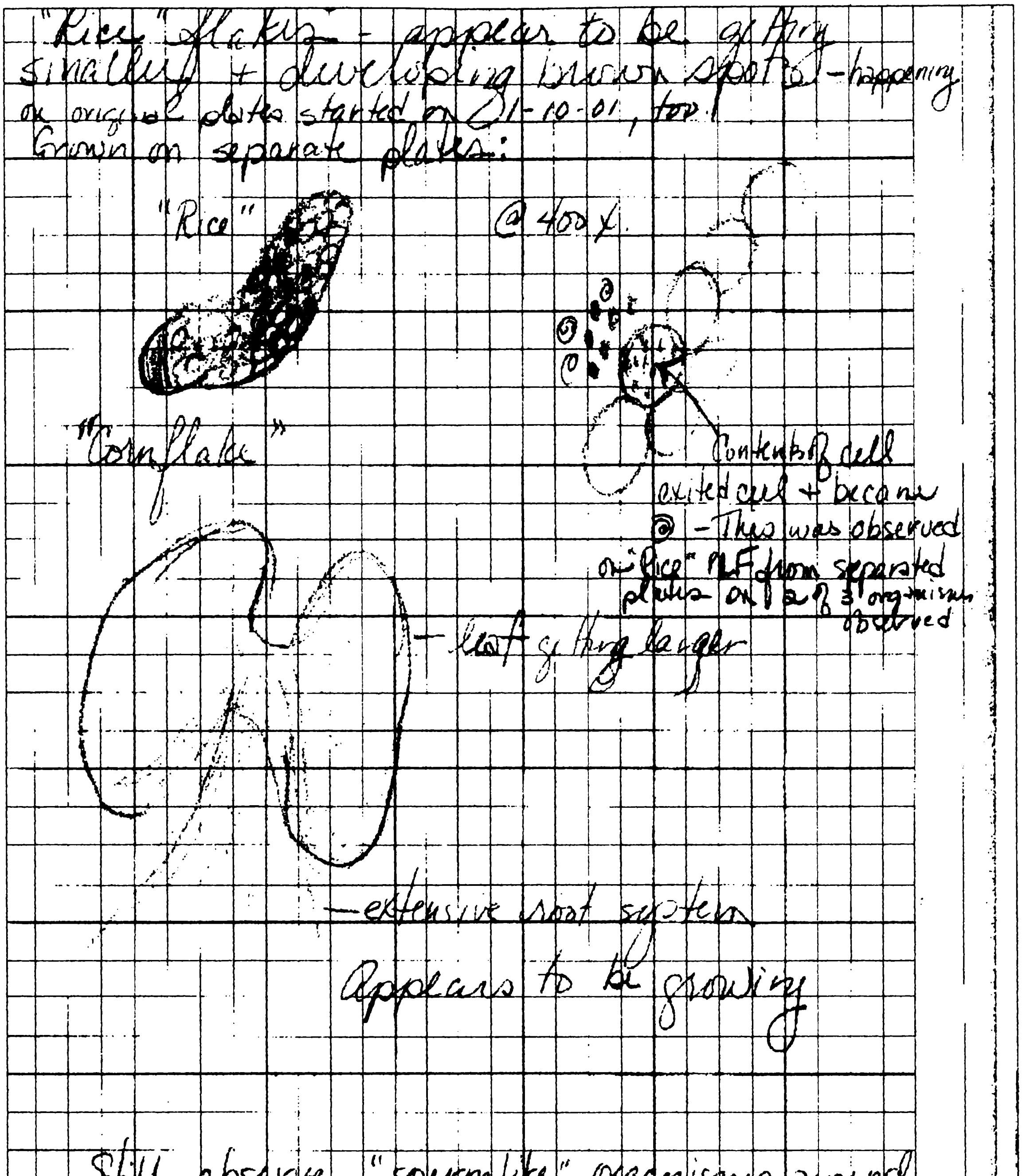


Figure 28: Susan's Diagrams of C-Fern Growth Patterns

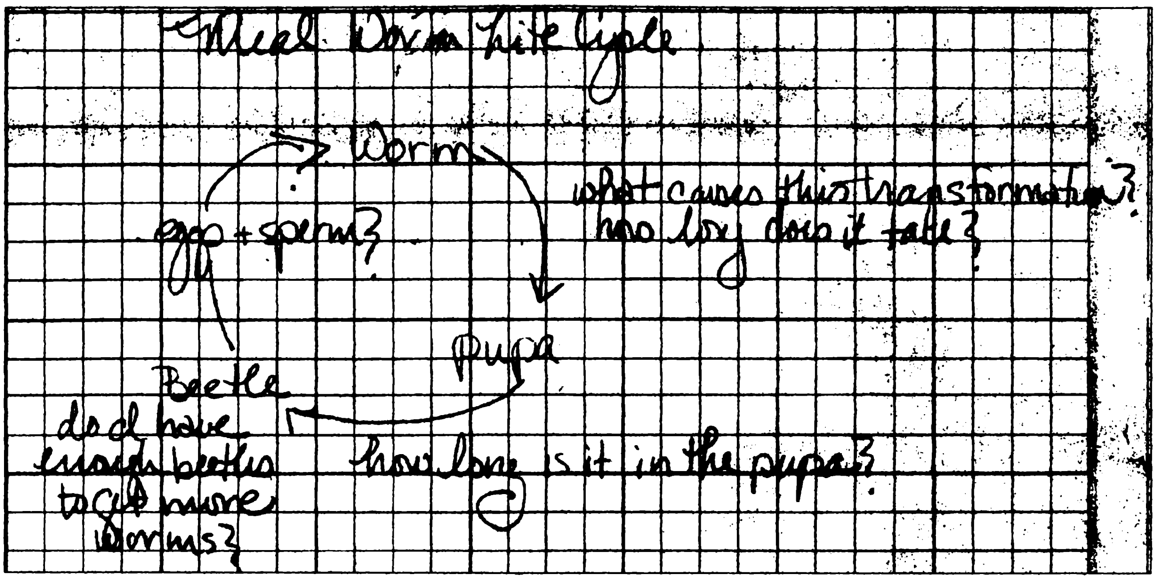


Figure 29: Susan's Diagram of Mealworm Life Cycle

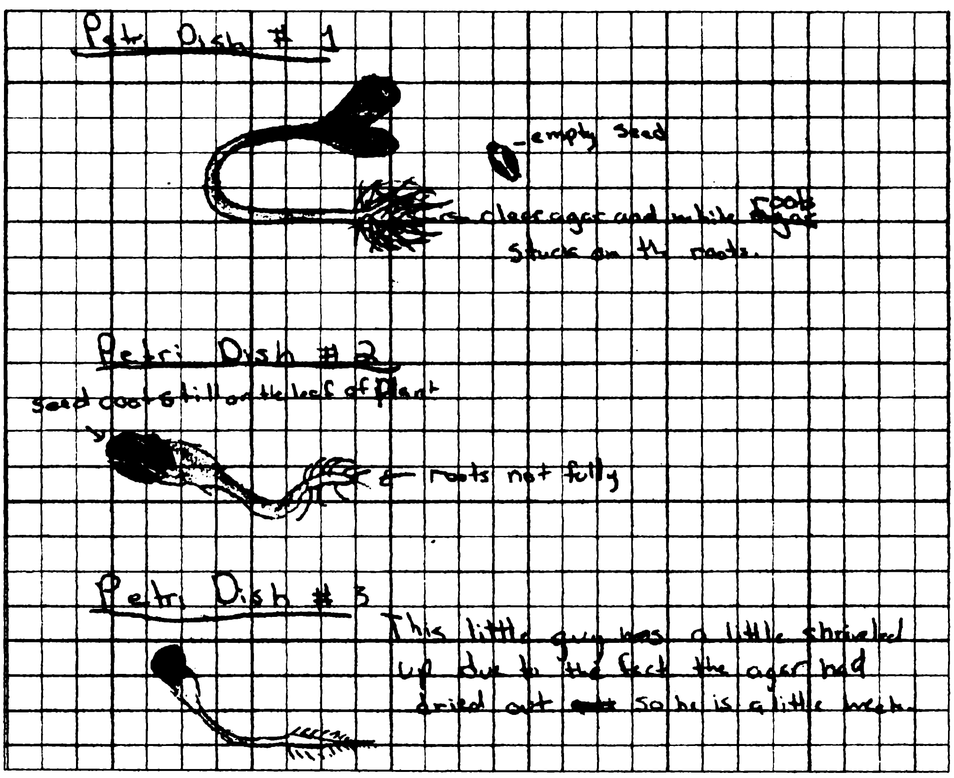
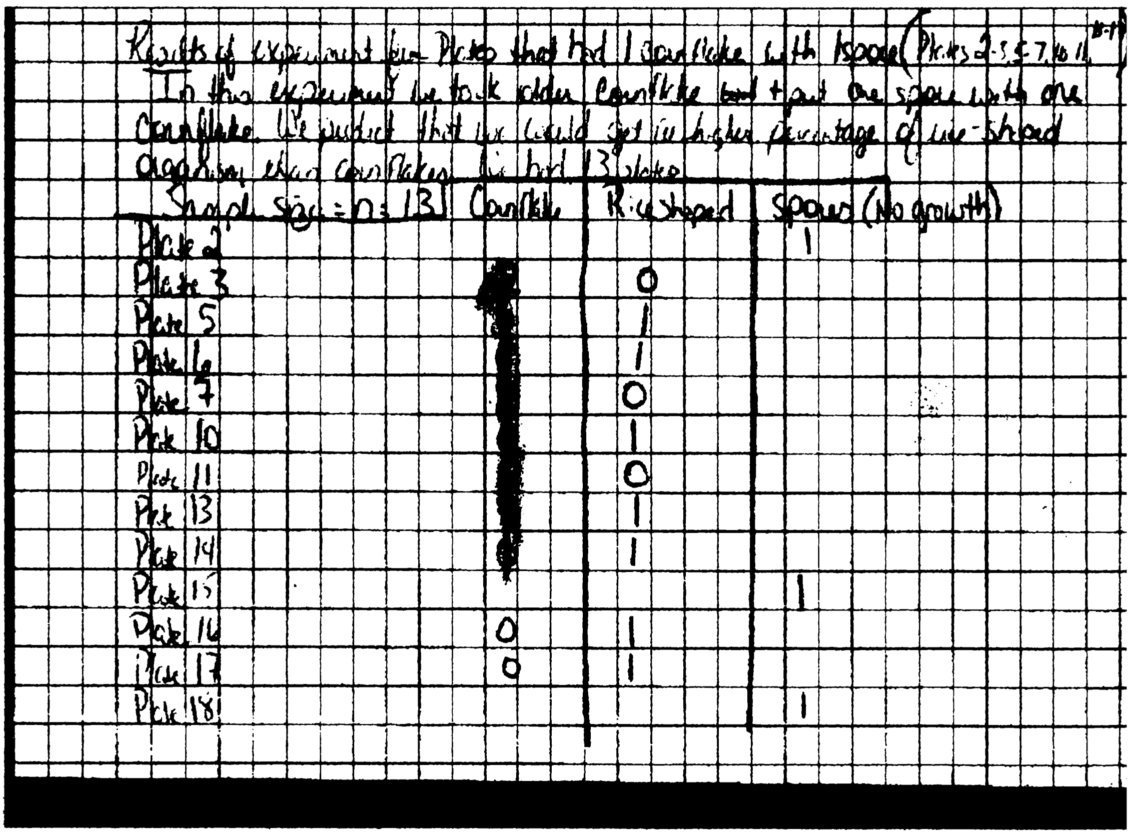


Figure 30: Basma's Diagram of Germinating Sunflower Seeds

presented and discussed as examples. Veronica prepared a table detailing which of the two C-Fern™ gametophyte growth forms she observed on a series of 17 Petri dishes. She noted her sample size as "n=13" and recorded the results in a series of columns. This table is reproduced in Figure 31. Alice transformed (see below) some similar data into a pair of pie charts which appear in Figure 32. She had calculated percentages of growth forms on two Petri dishes in order to prepare the pie charts. The participants recorded dozens of other examples of data charts and tables as well.



Sample Size = n=13	Cornflake	R-shaped	Spores (No growth)
Plate 2			1
Plate 3		0	
Plate 5		1	
Plate 6		1	
Plate 7		0	
Plate 10		1	
Plate 11		0	
Plate 13		1	
Plate 14		1	
Plate 15			1
Plate 16	0	1	
Plate 17	0	1	
Plate 18			1

Figure 31: Veronica's Data Table

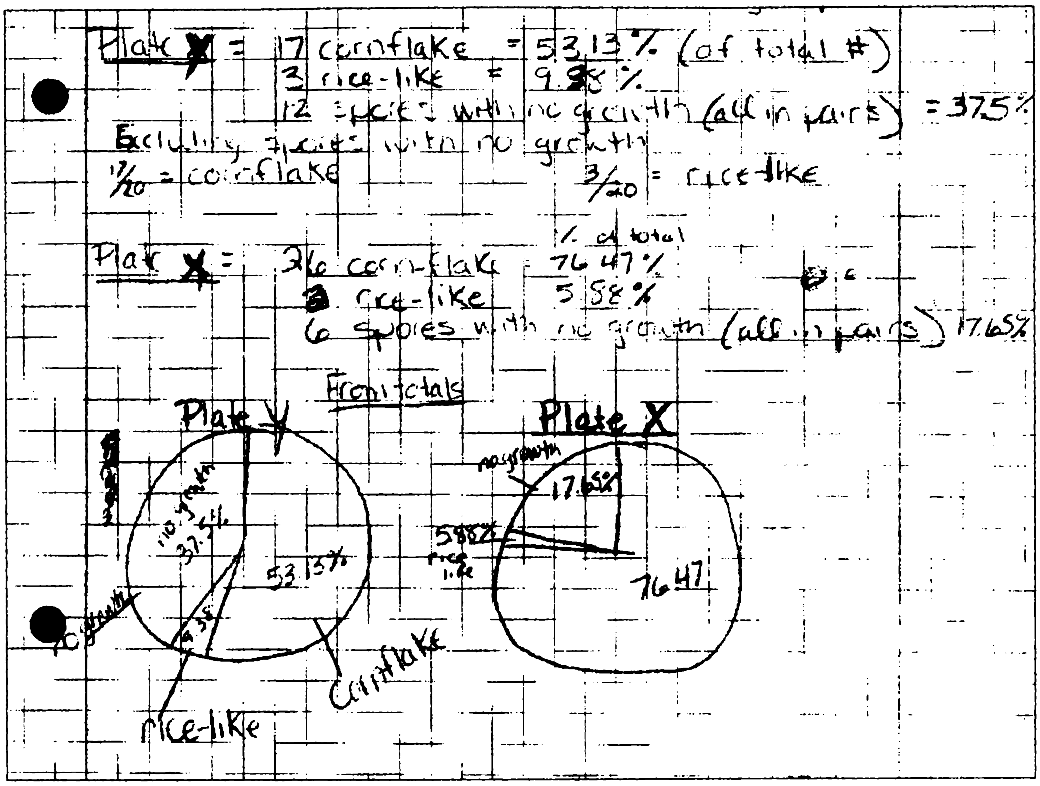


Figure 32: Alice's Pie Charts on C-Fern Growth Data

Mathematical formulas and equations. Very few purely mathematical inscriptions were recorded by the participants. The artifacts dealing with mathematics generally showed that the students tended to incorporate mathematical concepts into other types of inscriptions. For example, some participants recorded means, ratios and percentages (see Figure 32, above) as part of inscriptions that did not focus particularly or exclusively on mathematical concepts. Only three cases of purely mathematical inscriptions were found among the participants' laboratory inscription notebooks. These inscriptions had to do with preparation of chemical solutions and reagents used by the participants during their inquiry activities. Morgan and Ralph each recorded a formula for mixing sodium chloride solutions in various millimolar concentrations. Morgan's formula is reproduced in Figure 33. Alice and Veronica prepared a similar equation to help with them with the preparation of solutions of urea. The equation recorded by Alice is shown in Figure 34. Members of another cooperative work group recorded formulas and equations detailing preparation of sulfuric acid solutions of various pH levels for their experiment involving acid rain. Their inscriptions, not shown, were similar to those of Alice and Morgan.

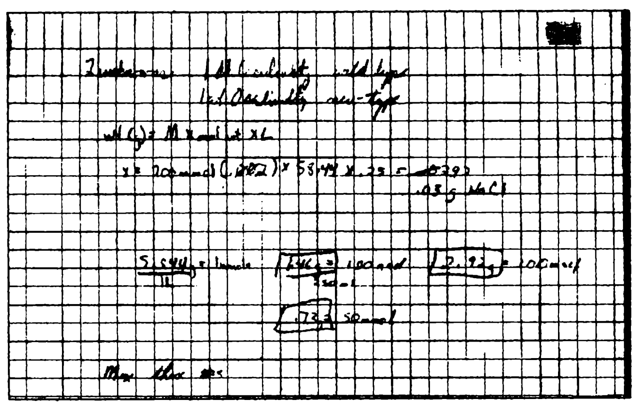


Figure 33: Morgan's Formula for Preparing Sodium Chloride Solutions

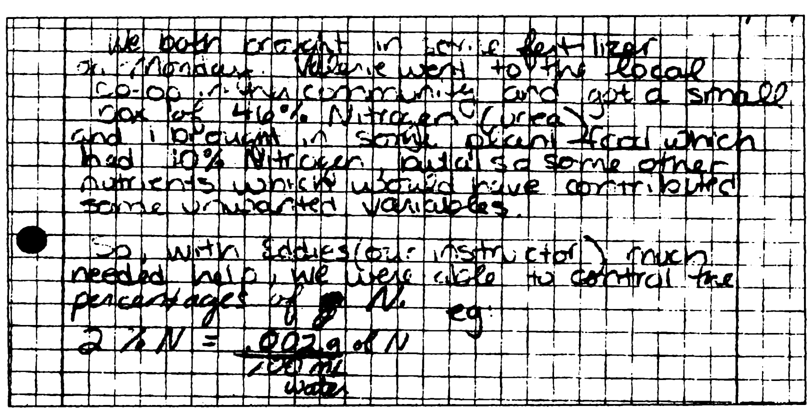


Figure 34: Alice's Formula for Preparing Urea Solutions

Graphical inscriptions. Graphical inscriptions were recorded very often to summarize data from an on-going or completed experiment. In fact, every participants' notebook and/or research paper draft included examples. Notice that in Figure 32, discussed above, Alice transformed some data from her table of germination results into a pie chart. A very polished bar graph, generated by computer, from Alice's research report on C-Fern™ appears in Figure 35. In this figure, numbers of the two gametophytic growth forms on a control Petri dish are compared. Phillip, Richard and Greg completed an experiment that yielded similar types of data. Phillip drew a graph in his laboratory notebook to summarize this data. Phillip's graph (Figure 36) is hand drawn but displays information in as great detail as that of Alice's computer generated graph. In both cases, individual numbers of the gametophytic growth forms are compared.

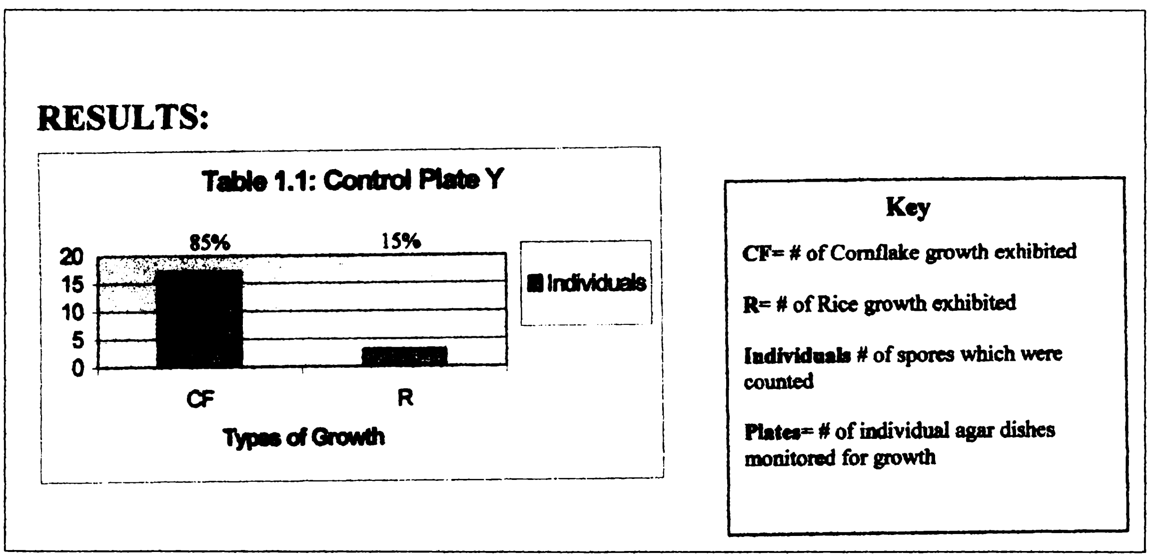


Figure 35: A Graph Appearing in Alice's Research Paper

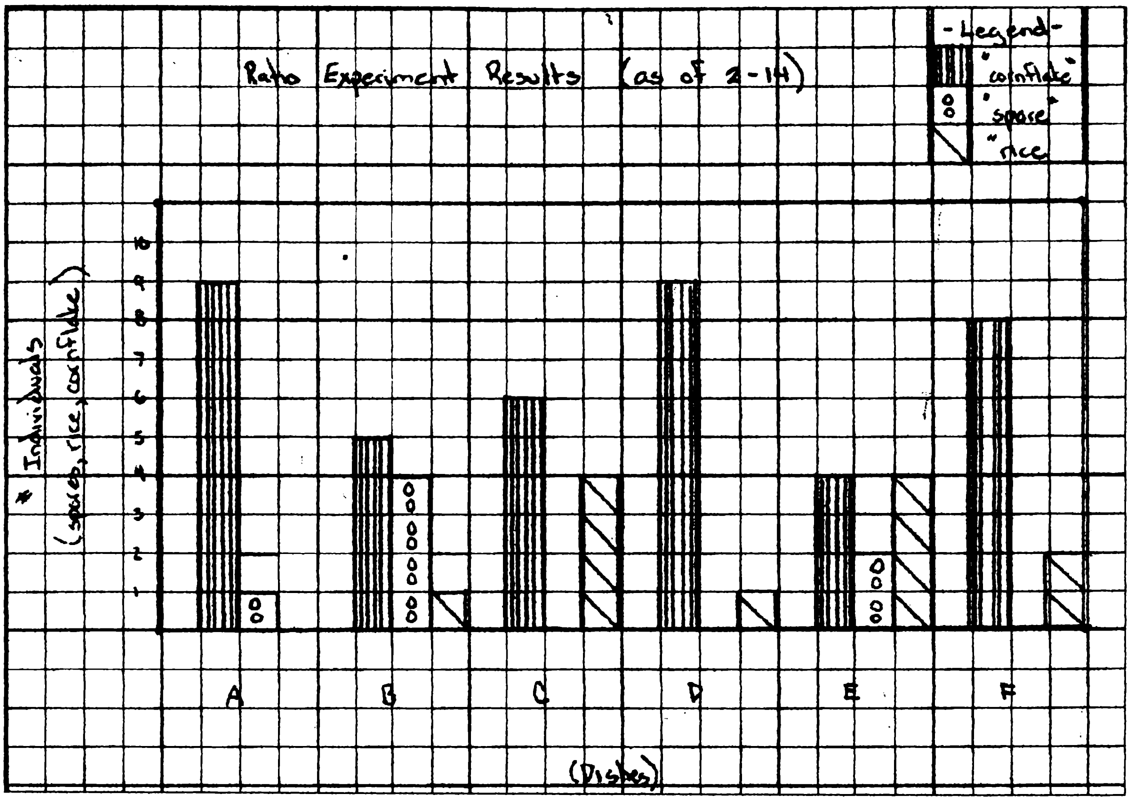


Figure 36: A Graph From Phillip's Laboratory Inscription Notebook

Examples of Socially Generated or Socially Shared Inscriptions

One example of a socially generated inscription, which was made during a whole-class discussion, has already been presented (see Figure 14) in a previous section of this chapter. In this case students responded to the authors' question "What makes a good experiment?" and the resulting responses were listed on the board. It is of note that every participant included their own variation of Figure 14 in their laboratory inscription notebooks. A noteworthy example of a socially used inscription is the map Alice and Veronica displayed during their inquiry lesson presentation (Figure 15). This map was described in a previous section of this chapter and was used to involve the other students in a lesson concerning the effects of urea on growth of rye. Further, as described in Table 2, Ralph and Morgan used their own graphs, and graphs drawn by other participants, to facilitate a discussion of their experimental data. Further, these graphs fostered a discussion of which types of graphs are most appropriate to display certain types of trends when interpreting data. Many other students used tables, charts, graphs and diagrams during their inquiry and inquiry lesson presentations. Some were made "on the spot" on the blackboard during the presentation. Others were in the form of posters or handouts prepared ahead of time. Some of the posters were placed on the bulletin board in the classroom where they remained for several weeks. Other inscriptions were used in research papers, which were given to Dr. Temple for grading.

Another previously discussed example of a socially generated or socially shared inscription is worthy of further detailed consideration. As was described in a previous section of this chapter, several students collaboratively drew a diagram of an emerging C-Fern™ sporophyte on the chalkboard. The construction of this inscription spanned most of the three hour class meeting during which it was produced. The construction of the inscription is described in detail in Table 6 (lines 66 - 251). The diagram was initiated voluntarily by Richard when he observed a slide under the microscope that had been prepared by Morgan and Ralph. Richard believed he had found spermatozoon transport canals in the specimen. Three students, including Richard, were directly involved in adding to and refining the diagram. All ten students were at least peripherally involved in discussion. Further, Dr. Temple, the course instructor;

and Eddie, the author and teacher assistant, interacted with the students about their observations and ideas as the diagram took shape (see Table 6 lines 73, 87 - 91, 106 - 116, 126 - 199,). The emerging diagram became the focus of the students' and instructors' discussion and activity. The term "conscription" has been used to describe an inscription that takes on such a high level of social importance during its construction (Roth, 1995). The diagram of the C-Fern™ gametophyte and emerging sporophyte, unfortunately, does not survive as an artifact from the course.

In the participants' laboratory inscription notebooks, numerous examples of socially generated or socially shared inscriptions were observed. A particularly noteworthy representation from Phillip's notebook is shown in Figure 37. Note that Phillip took a preliminary mealworm life cycle diagram directly from Susan's notebook (Figure 29) and credited her as the source. The reader should be reminded at this point that a whole-class discussion concerning the students' observation of their mealworm cultures is reproduced in Table 3. Note that in lines two through eight the students orally reported their observations regarding changes in the appearance of their mealworms. During the resulting discussion, Dr. Taylor explicitly asked the students about their past experiences with studying metamorphosis (see line nine). Following this discussion, Phillip made some written statements concerning the mealworms in his laboratory inscription notebook. Two weeks before the inscription shown in Figure 37 was generated, he wrote "Shed their skins on top of the bran" and "Several have gone into a pupal stage" in another

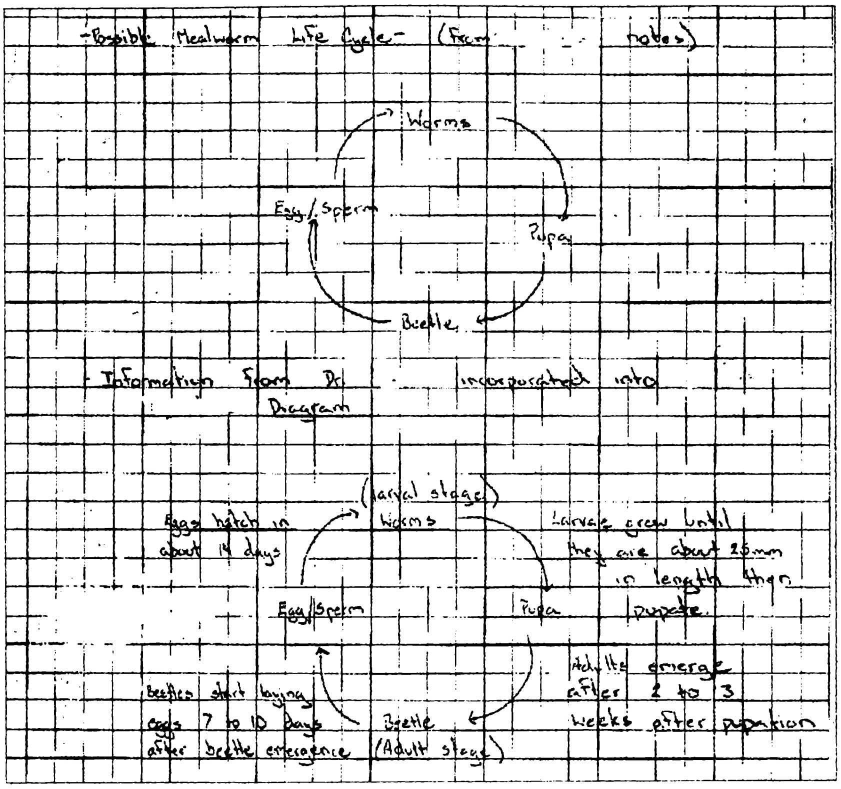
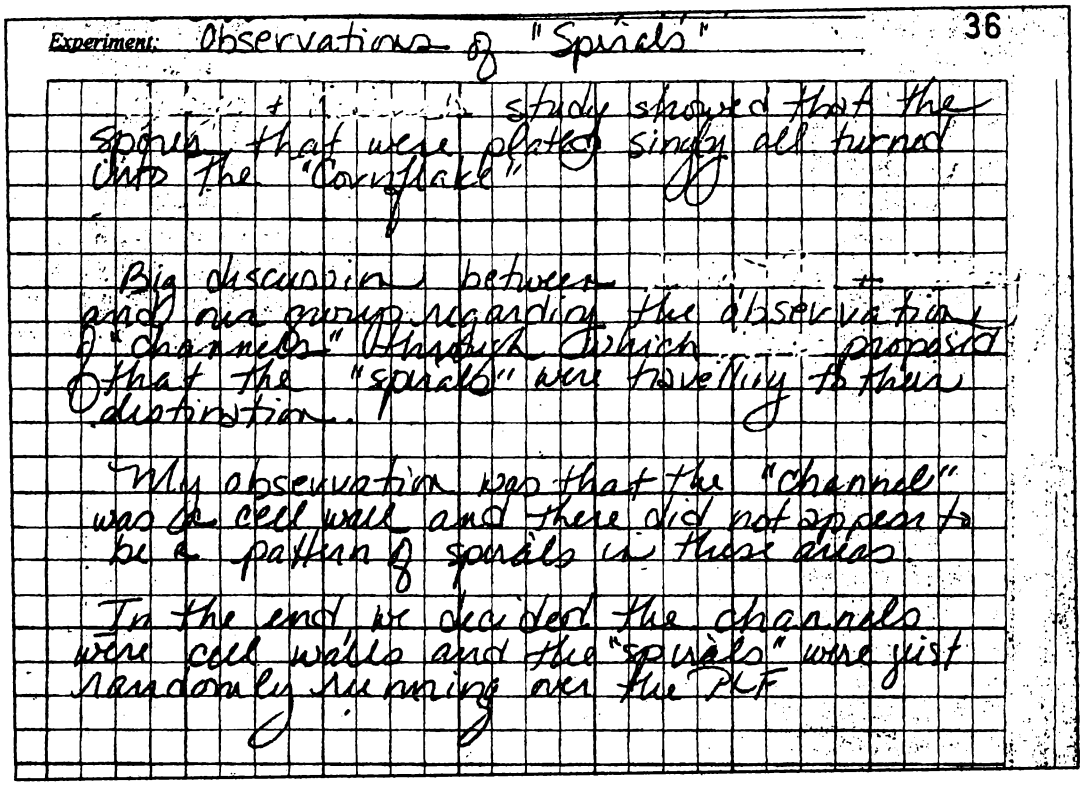


Figure 37: Phillip's Socially Generated Mealworm Inscription

inscription. One week later Phillip recorded the observation that "Pupae are starting to emerge. They look like little beetles." Phillip apparently did additional library or internet research on the mealworm and discussed his observations with Dr. Taylor. All of this social interaction combined to help Phillip produce the final and more detailed diagram of the mealworm life cycle, which is included in Figure 37.

A written inscription from Susan's notebook that she titled "Observations of Spirals" is reproduced in Figure 38. Notice that Susan writes about the observations of several other students in the class concerning the spermatozoa (the participants called them "spirals" or "squiggles") of the C-Fern™.



Experiment: Observations of "Spirals" 36

study showed that the spores that were plated singly all turned into the "Cornflake"

Big discussion between and our group regarding the observation of "channels" through which proposed that the "spirals" were traveling to their destination.

My observation was that the "channel" was a cell wall and there did not appear to be a pattern of spirals in these areas.

In the end we decided the channels were cell walls and the "spirals" were just randomly running over the PLF

Figure 38: Susan's Socially Shared Observations

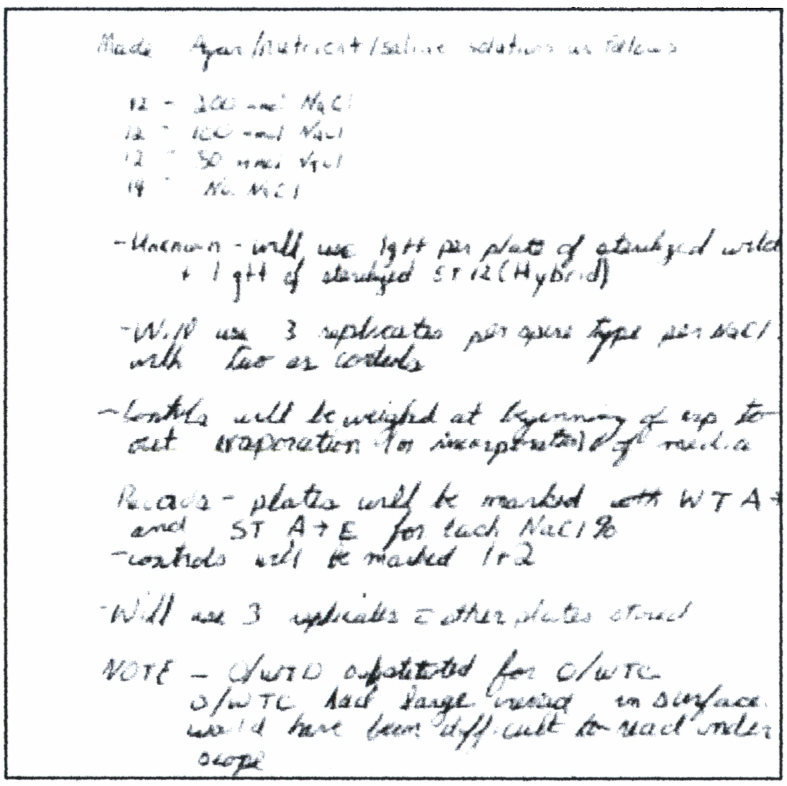
Interestingly, Susan also writes about the discussion described above (and reproduced in Table 6) concerning Richard's claim that he had found transport canals within a developing C-Fern™ sporophyte. She notes that the issue was collaboratively considered and resolved.

Examples of Transformation Cascades

Several examples in which students combined more basic and concrete inscriptions into more complex and abstract ones have already been mentioned and presented. In review, recall that Alice transformed tabular data concerning fern growth into a pie chart (Figure 32). She also recorded incidence of the two gametophytic growth forms of C-Fern™ in a computer-generated graph (Figure

35). Phillip also transformed raw data on C-Fern™ gametophyte forms into a graph (Figure 36) and used a variety of sources to prepare an ultimate diagram of the mealworm life cycle (Figure 37).

For purposes of additional clarity one further detailed transformation cascade is worthy of consideration as an example. It is presented in Figures 39 through 44 and is the product of an experiment completed by Ralph and Morgan. Figure 39 is a general overview of the experimental plan in which Ralph and Morgan compared the growth rates of C-Fern™, grown in agar mixed with various concentrations of sodium chloride solution. Two genetic strains,



Made Agar/Nutrient/Saline solutions as follows

12 - 200 mm NaCl
12 " 100 mm NaCl
12 " 50 mm NaCl
14 " No NaCl

- Unknown - will use 1 gtt per plate of sterilized wild + 1 gtt of sterilized ST 12 (Hybrid)

- Will use 3 replicates per spore type per NaCl with two as controls

- Controls will be weighed at beginning of exp to cut evaporation (or incorporation) of media

Records - plates will be marked with WT A + and ST A + E for each NaCl %
- controls will be marked 1 + 2

- Will use 3 replicates c other plates stored

NOTE - C/WT D substituted for C/WT C
C/WT C had large crease in surface
would have been difficult to read under scope

Figure 39: Ralph & Morgan's Transformation Cascade: The Plan

wild type (WT) and a hybrid identified initially as ST-12 (ST) were used in the study. In Figure 40, notice that Ralph recorded "measurements." This data came from measuring the length of the C-Fern™ gametophytes when grown in agar prepared with zero, 50, 100 and 200 millimolar concentrations of sodium chloride solution. Ralph's laboratory inscription notebook contained eight pages of measurement data recorded in this fashion on various days during the experiment. The example shown below in Figure 40 also includes a diagram of the "longest leaf" and a reproduction of the microscope's measurement graduations.

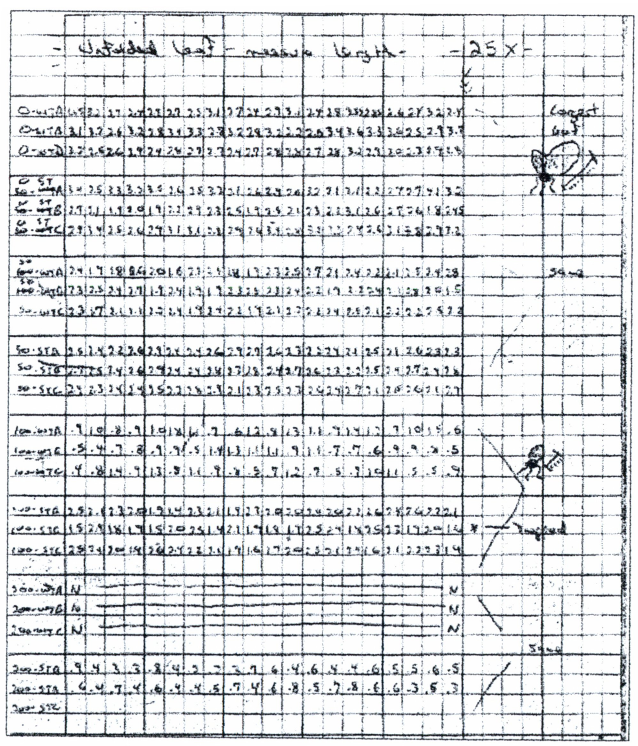


Figure 40: The Measurements

In Figure 41, notice that Ralph and Morgan calculated percentages of germinated spores from four WT samples and four ST samples. In their inscription, they labeled the main data columns as "germination results" and recorded percentages of germinated spores from their data. As the data began to accumulate, the students used computer-assisted technology to generate statistical summaries of the data. One example is shown in Figure 42. The data were next transformed into a penultimate series of bar graphs, which appear in Figure 43.

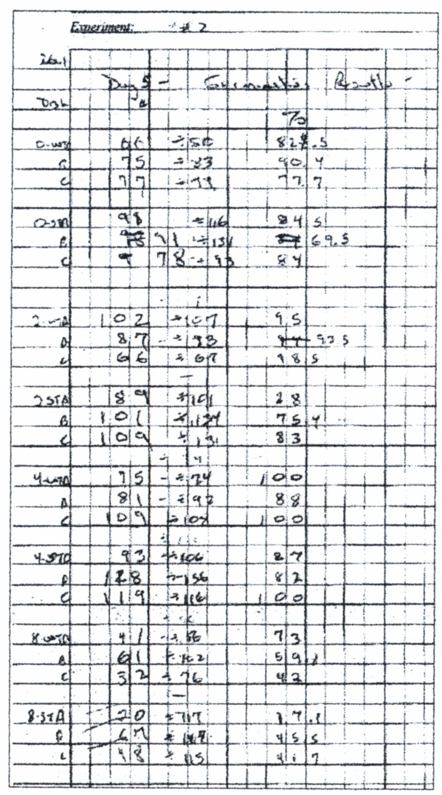


Figure 41: The Results

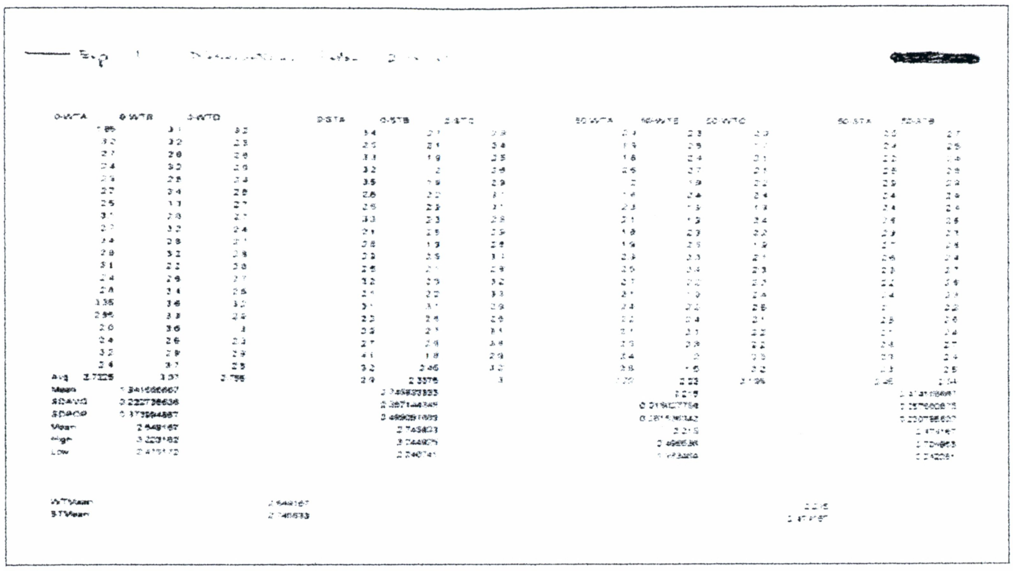


Figure 42: The Statistics

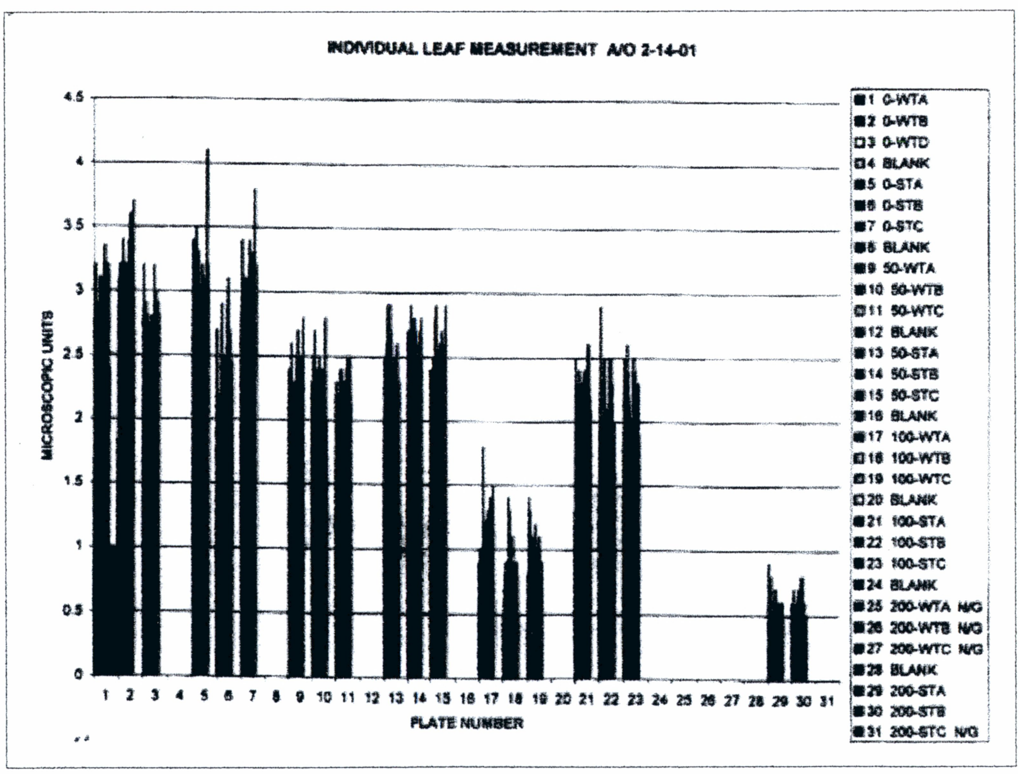


Figure 43: Penultimate Bar Graph

The ultimate transformation of the data from Ralph and Morgan's experiment is a line graph, made partly on computer with the data points neatly connected by hand. This graph compares the growth of two C-Fern™ genetic strains, wild type and salt tolerant, in varying concentrations of sodium chloride. This graph appears in Figure 44. The reader should recall that, by the time this graph was produced, Morgan and Ralph had correctly identified the hybrid strain (ST) as salt tolerant. They based this conclusion on their own experimental data. Ralph and Morgan included this line graph in their written research report. They also used a larger reproduction of the graph during their oral research report.

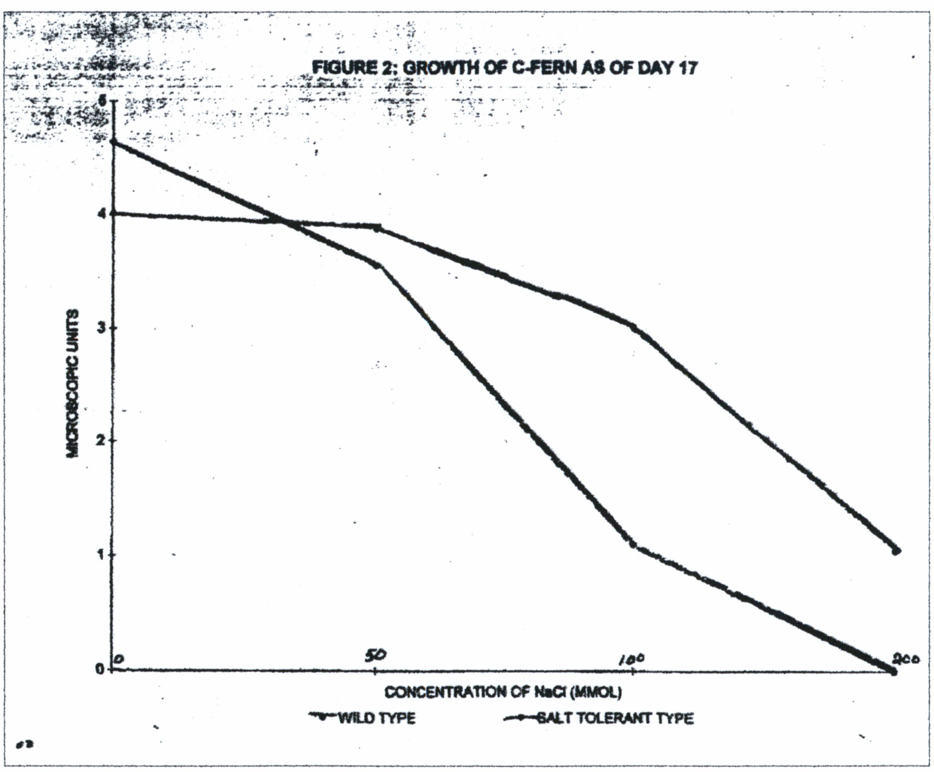


Figure 44: Ultimate Line Graph

The above section of this research report has dealt with evidence related to the third research question posed in Figure 11: What are some examples of scientific inscriptions students recorded during their experiences? This section has presented examples of inscriptions recorded by the participants during their involvement in guided and open inquiry activities in the "Knowing and Teaching Science: Just Do It" course. The students generated hundreds of inscriptions while working with the knowledge that their laboratory inscription notebooks would be graded according to the rubric shown in Figure 9. The next section of this research report will consider the effect of the students' shared experiences of participating in an inquiry-based science course and in the activity of recording inscriptions on their ability to design and carry out successful experiments over time.

Question Four: Will participation in an inquiry-based science course, and in the activity of recording inscriptions, improve students' ability to design and carry out successful science experiments over time?

Figure 45 provides an overview of the results relating to the above, fourth, research question. Thus far, the results presented have established that all ten student participants in the research study shared a number of experiences during their enrollment in the "Just Do It" course. Two primary shared experiences are of interest in the present section of this chapter. These experiences are engagement in inquiry-based activities and the regular recording of scientific inscriptions in the laboratory inscription notebooks. With the assumption that the consideration of these two shared primary experiences is sufficient, the above research question will be evaluated in terms of two

Question 4: Will participation in an inquiry-based science course, and in the activity of recording inscriptions, improve students' ability to design and carry out successful science experiments over time?

I. Participants' Reports to the Author on Performance
  A. Comments About Participating in Inquiry Activities
  B. Comments About Recording Inscriptions in the Laboratory Notebook
  C. Comments From Members of a Previous Cohort

II. Participants Performance
  A. A Word About Evaluating Performance
  B. A Comparison of Performance Over Time
  C. Additional Notes on Student Performance

III. Concluding Remarks on Results

Figure 45: Overview of Results Relating to Question 4

sources of data. First, the participants' reports to the author about how participation in inquiry and recording of inscriptions influenced their success will be considered. Second, the participants' actual performance in designing and carrying out successful experiments will be considered.

For purposes of this study, a "successful experiment" is defined as one in which a concise research question and a clear, testable hypothesis have been stated. Also, the definition requires that the experiments have a control, that an adequate sample size is used and that the results of the experiment are interpreted in terms of comparing the experimental group(s) to the control group(s). Further, the experiment should yield some useable results. An "adequate sample size" is problematic to define. Generally a large sample size is preferable to a small one. Also, "useable results" is problematic to define. Generally, the results will be considered to be "useable" if they are reported to have been used (in this study) to write a research report, to prepare an oral presentation or to prepare an inquiry lesson. More specific comments about the criteria by which the participants' experiments were evaluated in this study are presented in a later portion of the current subsection of this chapter.

Participants' Reports to the Author on Performance

Specific comments from the research participants, and from members of a previous cohort of students who enrolled in the "Knowing and Teaching Science: Just Do It" course are shown and considered below. These comments concern the usefulness of participating in inquiry-based experiences, and of recording scientific inscriptions, in helping to design and carry out successful experiments over time. Figure 46 presents a general summary of the participants' ideas and responses regarding the above research question.

Comments about participation in inquiry activities. During the concluding interview, all of the participants who were asked verified the author's initial premise that they felt more at ease thinking of and carrying out successful experiments as time went on. It is a generally accepted notion that practice with most any task fosters competence and comfort. However, the participants had a number of noteworthy things to say regarding this issue that suggests an additional level of complexity. The comments shown below have been extracted from concluding interviews, post-class interviews and from other sources.

> Susan: For some reason students get in the mode of wanting to know the right answers. I think they get away from asking questions and being curious about things. That's just the way school is. So that drives

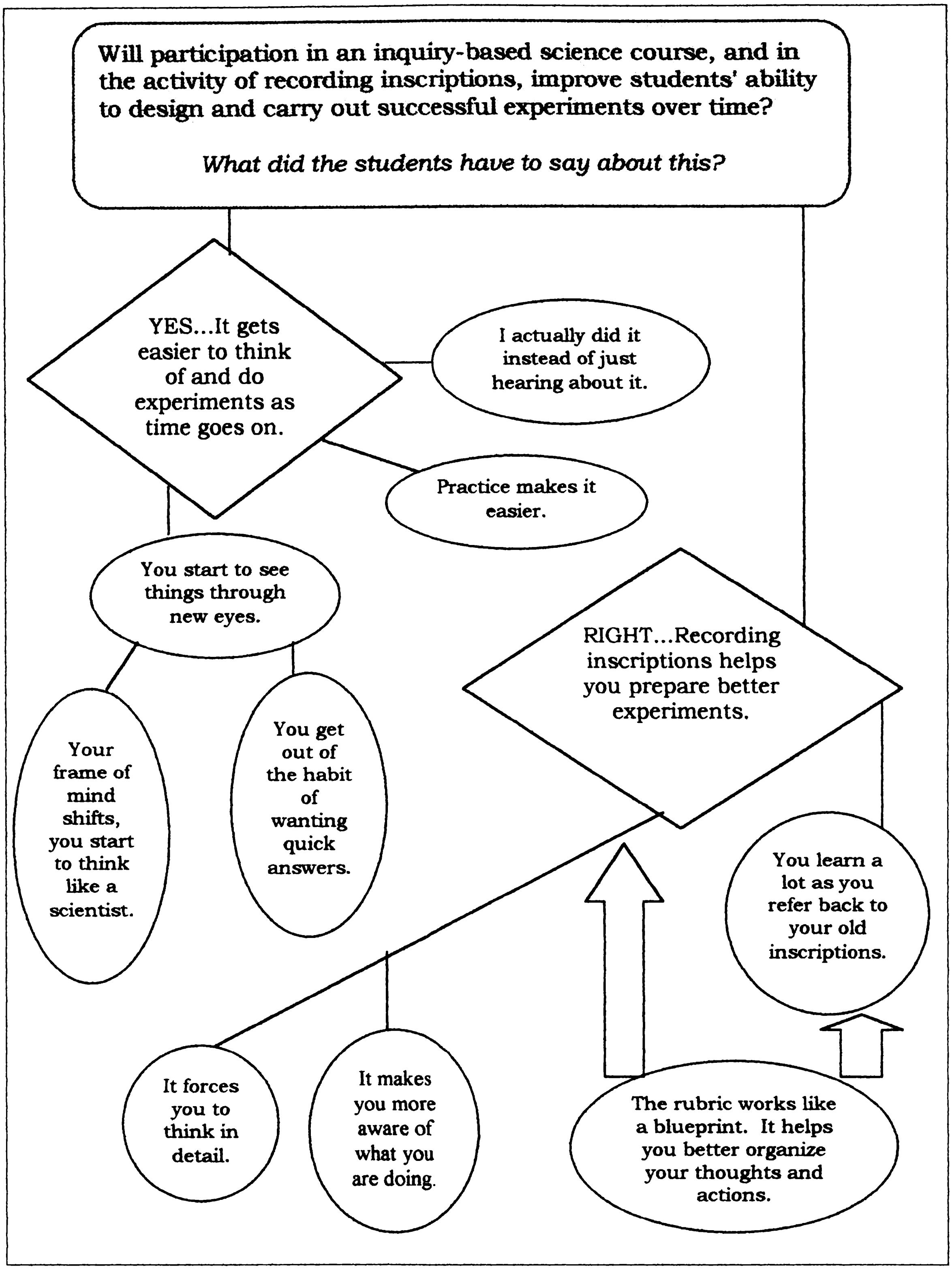


Figure 46: Summary of Reflections on the Effect of Participating in Inquiry and Recording Inscriptions

the good student away from questioning. So once we got in that mode of asking questions it became a little easier.

Sara: It got easier because we were getting into that frame of mind. I think inquiry, open inquiry, is almost an acquired taste. Because I think you kind of have to train your mind to think that way. Even in my undergraduate labs we were given that cookie cutter lab and we went through it. We got the right answer and we left. So you have to train your mind.

Greg: Well, you just start thinking about things and they build upon each other as time goes on. You start to wonder about other things.

Richard: I think everybody's confidence has really improved. Everybody has made some really important observations and everybody has shared information within the lab. In the other courses that I've had...it's been a step by step procedure and the answer is already given to you if you look a page further in the lab manual. You know, and if you missed step one you have to start...back over or you're not gonna have the end result that is expected. I don't think that /// allows a student to think on his or her own.

Sara: Going through the class I think that /// I've learned a lot more about the scientific method. [Eddie asks, "So you feel like this class helped you to understand it?"] Absolutely. Having to do it myself and the way it was presented to me...We were taught to teach science through learning science again through new eyes.

Basma: Actually I think I have [the scientific method] straight now because of this course. And I know that you have to develop an experiment and have a control and a hypothesis because without those you really don't have an experiment.

Veronica: After that first experiment that Alice and I did, the second was easier, the third was easier. It got easier as the time went on.

Morgan: I got a chance to do it hands-on, personally. It will be easier to remember next time. Maybe next time I won't have to have somebody looking over my shoulder to make sure I do everything right.

Susan: I really didn't understand the difference between cookbook science and doing things that everybody already knows what is going to happen... verses starting out with a lot of items and developing their own studies, making observations on their own.

Ralph: I don't think my viewpoint of the scientific method has changed. What might have changed though is the specifics and the methodology /// becoming more focused and putting things together in some sort of logical order.

Veronica: With the scientific method what we basically had to know about that was just the overall points of it and just kind of memorization. With [the Just Do It course] we have actually done it. With me, it is easier for me to remember stuff once I have actually done experiments /// you know, something that I always have.

Richard: This type of course really makes a student become much more investigative and seek knowledge rather than memorize just for the sake of making a good grade. It is easy to see that we have become much more critical of the experiments we have discussed.

<u>Comments about recording inscriptions in the laboratory notebook.</u> All participants in the concluding interview agreed with the author's initial premise that the act of recording inscriptions helped them to prepare better experiments. In addition to that, the students reported that they often referred to previously recorded inscriptions in their lab notebooks when considering future experimental designs. Supporting comments, from various sources, are listed below.

Susan: You are made more aware of making observations and keeping notes on things. The benefit of inscriptions is the ongoing record that will help thinking along the way.

> Morgan: It helped me stay organized for one thing. As it went on I'm sure you could probably tell that the experimental design got a little bit better each time. And one part of that is having a written record of what, exactly, we did the first time and you could see the progress as it went on. [I referred back to the inscriptions] many, many times. I had to go back, read a little bit and find out exactly [what I observed].
>
> Alice: Every time that Veronica and I would do our conclusion we would see reasons why the results turned out one way or why they didn't. So as time went on we'd try to eliminate those variables. So I think [the lab notebook] helped. We would base experiments on other experiments that we had done. We were always looking back.
>
> Basma: We always went back to our inscriptions after we started to make a new experiment to see what went wrong in the first one so that we could improve it. So that's what really helped. Also, having in our notebooks what other people had done and what went right and wrong with theirs also helped.
>
> Sara: The act of writing down /// The inscription notebook forces you to think through everything in a very detailed manner. Making the inscriptions helped me to be more detailed and therefore prepare better experiments.
>
> Greg: We'd go back and refer to our data for experiments on down the road. It was a good reference. One idea springs from another experiment.
>
> Basma: I can look at my inscriptions now to see how did I think when I first started this class and how do I think now. It will give me a good background.

<u>Comments from members of a previous cohort.</u> As was described in the methods chapter of this research report, Chapter Three, the author held a focus group with three members of a previous cohort of students from the "Just Do It" course. The reader may recall that these students had completed the course without explicit instruction on inscriptions and without exposure to the rubric

used to evaluate the laboratory inscription notebooks (Figure 9). These participants, at the time of the focus group, had been recently exposed to these ideas in another course. Therefore, the author believed, these three students would have a unique perspective about the potential role that recording inscriptions may have had in their "Just Do It" course experience.

All three participants in the focus group noted that the inscription evaluation rubric and the explicit instruction on inscriptions gave new names and terminology to an old practice of writing down data and observations. However, two of these participants expressed a belief that seeing the rubric and actually recording inscriptions with their new-found terminology brought a different and deeper, though subtle, dimension to their work as scientists. Interestingly, two participants used the word "blueprint" to describe the evaluation rubric (Figure 9) and all three described how it helped them to organize their thinking. Excerpts from the focus group are presented below.

> Eddie: Is there a difference in how you've used that concept [of inscriptions] now verses in "Just Do It?"
>
> Frank: The rubric that [our teacher] is using now to grade our inscriptions is totally different than it was in the "Just Do It" class, I think. We pretty much wrote everything that we did down, made all of our observations, whatever experiments we're doing, make tables and graphs and charts. But we never called it those things. We were doing that all along it seems but it never was that organized and categorized like in the rubric now. It's like we've got a blueprint to use. I thought I was good at organization but it doesn't seem like I am. Like those transformation cascades /// As to going back and tying everything together or making it all seem coherent.
>
> Eddie: Did you do that in "Just Do It?" Did you make those transformation cascades?

Frank: I would refer to a previous experiment or refer to what Sam or Mary found out. That's what I would do but in this it seems you have to bring the information up in a graph or a table or make a big cycle. You know, it seems you have to do more.

Eddie: So you do more but it is better or worse?

Tanya: I would say it's just in the name. I'd say we did all of those things before but we didn't label them. It's more organized now but everything was there before.

Frank: I think it's much better.

Sam: The terms are new. I like it. I've been doing it all along but it's a better way to organize.

Eddie: I think I'm hearing two different things /// Is it fair to say the two things just have different names?

Tanya: I /// I think so /// basically.

Sam: I believe that is fair but>>>

Frank: No /// the rubric helps. It gives you a blue-print. That's good. But I'm also thinking we got introduced to it, but now we're being more specific.

Sam: Rather than at the beginning, somewhere along as we were working that would have been something good to throw out and say "here's another way to organize." That would have been better /// a step we could have progressed in.

Tanya: I agree. If we got it as we were into an experiment, it would help organize things for us.

The above subsection has presented comments from the participants, and from members of a previous cohort of students, about how useful participation in inquiry activities and in the act of recording scientific inscriptions were in helping to design and carry out successful experiments over time. The subsection presented below presents some examples of the ten primary research participants' actual performance over time.

Participants' Performance

A word about evaluating performance. Most traditionally minded scientists operate within a positivist or neo positivist paradigm. In very general terms, these scientists assume that reality exists as an entity that is independent of researchers. The goal of research in this paradigm is to discover or verify reality by way of controlled experimentation. Replication of such experiments, as well as peer review of research findings, are regarded as ways to insure efficacy (Guba, 1995). As has been described, students were taught and evaluated with the principles of positivism and/or neo positivism in terms of their research activities in the "Just Do It" course. It is the author's belief that evaluating research even in the most strict positivist paradigm involves much subjectivity. There are no fast rules about sample size, statistical tests and interpretation of results. In actual communities of scientific practice, one professional journal may reject outright a research paper that has been submitted on the grounds that it does not conform to accepted principles of sound scientific research. Another journal may embrace the same research paper and anxiously publish it. The decision about efficacy usually falls to a small group of reviewers. Decisions about efficacy of the research participants' experiments in this research report are solely the author's. An effort has been made to keep the generally accepted principles of "good research" in mind that are consistent with the positivist/neo positivist paradigm (Guba, 1995) which were taught to the participants. In short, an experiment should have a well-honed question and a testable hypothesis. There should be a control for purposes of comparison. A larger sample size is better than a smaller one.

Conclusions should reflect results. Results should be replicated to insure validity of conclusions.

The author's original research design to evaluate the effect of participating in inquiry and maintaining inscriptions on the participants' ability to design and carry out successful experiments over time was significantly modified very early in the research process. The original plan was to ask the students questions about the scientific method and to ask them to verbally describe an experimental design during the pre-class and post-class interviews (see Figure 5). In general terms, the students did very well with these questions during the pre-class interview. Some students verbally described sound experiments, but often with only a small sample size. Only one student failed to mention or imply the need for an experimental control. One student, Ralph, seemed to be a bit puzzled by the author asking such elementary questions of a graduate student who held a degree in science.

> Eddie: I am going to show you some seeds from a popular decorative plant. How would you design an experiment to determine whether natural light or artificial light would cause a better growth rate of these plants?
>
> Ralph: Oh, you certainly don't want me to go through things like /// Do you want everything from the same soil, same moisture and so forth? Are you going to put one under UV light?

A second student, Basma, appeared puzzled as well, but in a different way. She laughed about trying to remember a concept she studied as a child.

> Eddie: What is the scientific method?
>
> Basma: Ooh [laughter] /// Those were the ones we did /// like in elementary school?

Eddie: Yea.

Basma: And in middle school there were seven /// which I can not remember off the top of my head.

Eddie: Ok. If you can't remember all the steps off the top of your head, can you just sort of summarize to me what /// what the scientific method is?

Basma: Yea /// What you're doing is /// you're taking something, you know, doing like a project or whatever and you just take it step by step. You observe it and then, you know, make a hypothesis. And then after that you just /// ah /// you know, you observe and look at it and see how it goes through and if it works well then you got yourself, you know, a theory.

Basma's response, though not totally incorrect, was probably the weakest of any of the participants. She went on to describe a fairly sound experimental design regarding the question of natural verses artificial light on plant growth. As Basma and the remaining students began to actually conduct their earliest experiments in class, however, the author found a strong incongruity between what the participants said they knew about science and how they actually performed as scientists. Therefore, the author partially abandoned his original plan to compare verbal descriptions of experiments voiced by the participants and decided to rely, instead, on the participants' actual performance.

A comparison of performance over time. In this subsection the author will compare three experiments each participant was involved in during their enrollment in the "Just Do It" course. The first experiment is defined as the earliest entry in the laboratory inscription notebook in which the participants explicitly referred to their work as an "experiment" or an "investigation." The second experiment is the set of entries immediately following. The last experiment is the final experiment recorded in the laboratory inscription notebook.

In considering the following evidence from the cooperative work groups, the reader should note that at about week ten of the course, two student work groups mutually agreed to change one member each. The two original work groups consisted of Richard, Phillip and Greg (one group) with Susan, Sara and Basma (the second group). Susan and Richard swapped places to form the two new groups.

1. Alice and Veronica. Table 7 compares the essential features of the three experiments for this group. These two students began their first "experiment" with at least seven explicitly stated research questions. Some of the questions were very general and open-ended and would have been difficult to answer by way of a scientific experiment. The students lacked any sort of control group for purposes of comparison. The experiment(s) was/were ultimately abandoned. The second experiment conducted by Alice and Veronica was more promising with one clearly stated question, a replicated control and 18 experimental replicates. The two students used the results from this experiment to expand into a third, related experiment. This experiment is not discussed in this section. The students' final experiment improved even more. The students had a large sample size and more carefully expressed their operational definitions. Further, this final experiment was used as the basis for the students' inquiry lesson. As previously stated, this experiment and inquiry lesson involved a study of the effects of varying concentrations of urea on the growth of certain types of grasses.

Table 7

A Comparison of Alice & Veronica's Experiments Over Time

Experiment	**Question**	**Control**	**Operational Definitions**	**Sample Size & Replicates**	**Conclusions**
First	7 stated, some very open ended	None stated or implied	None stated	8 plates with many organisms in each but no groups or separate treatments	None stated or implied
Second	1 clearly stated	Present and replicated twice	Clearly defined "growth form"	20 plates total with 18 experimental replicates and two control replicates	Reported differences based on comparison of experimental and control groups
Final	1 clearly stated	Present and replicated nine times	Clearly defined "growth" and "measure"	69 plants total, 10 in each of 6 experimental groups with 9 control replicates	Reported differences based on comparison of experimental groups with each other and with control groups

2. Ralph and Morgan. These two students began an "experiment" with no explicitly stated research question and no control. This first experiment also lacked clear operational definitions and explanations about experimental treatments. The experiment was quickly abandoned by Ralph and Morgan. The two subsequent experiments they designed improved dramatically. Both of these experiments had the common theme of investigating the effect of sodium chloride on the growth of plants. The participants correctly identified a second unknown genetic variant of C-Fern™ as being salt tolerant during their second experiment. The third experiment was used as the basis for the students' inquiry lesson. The comparison between the three experiments is summarized in Table 8.

Table 8

A Comparison of Ralph & Morgan's Experiments Over Time

Experiment	**Question**	**Control**	**Operational Definitions**	**Sample Size & Replicates**	**Conclusions**
First	None explicitly stated	None stated or implied	None stated	5 plates with many organisms in each but no separate treatments	None stated or implied, did record drawings of organisms
Second	1 clearly stated	Present and replicated three times	Clearly defined "growth" and "region measured"	12 plates total with multiple organisms in each, 3 plates in each of 3 experimental groups with 1 control per group	Reported differences based on comparison of experimental groups with each other and with control groups
Final	1 clearly stated	Present and replicated ten times	Clearly defined "growth" and "region measured"	40 pots total with 10 plants per pot, 3 experimental groups and 1 control group	Reported differences based on comparison of experimental groups with each other and with controls

3. Basma, Sara and Susan. These students swapped a group member with Phillip, Greg and Richard. The first experiment had a control but no explicitly stated question. They used two replicates of each of three groups. This experiment was abandoned. In the second experiment, they did have a clearly stated research question and increased their replication to three times. The experiment was regarded as successful and showed clear results. Basma, Sara and Richard joined for the final experiment. They reported that they had to "make do" with a smaller sample size than preferred due to problems with growing plants for the experiment. The experiment formed the basis for their inquiry lesson. The students identified water as being a variable they neglected to adequately control. These three experiments are summarized in Table 9.

Table 9

A Comparison of Basma, Sara & Susan's* Experiments Over Time

Experiment	**Question**	**Control**	**Operational Definitions**	**Sample Size & Replicates**	**Conclusions**
First	None explicitly stated	Present	None stated	6 plates with many organisms in each, 2 plates in each of 3 groups	None stated or implied, did record drawings of organisms
Second	1 clearly stated	Present	Clearly defined "germination"	6 plates with many organisms in each, three plates in each of two groups	Reported differences based on comparison of experimental groups with control group
Final*	1 clearly stated	Present and replicated 5 times	Clearly defined "growth, " "hot and cold" and "region measured"	15 plants total, 5 in each experimental group and 5 in control group	Reported differences based on comparison of experimental groups with each other and with control group

*[Note: Susan left the group and Richard joined by the time of the final experiment]

4. Phillip, Greg and Richard. These students swapped a group member with Basma, Sara and Susan. The first experiment had a research question that was too open-ended and did not lead to a testable hypothesis. There was no control. These students said the experiment was "inconclusive" and that they wanted to replicate the experiment with better control. They made no further attempts on their original research question. The second experiment had a more focused, scientifically sound research question but still no obvious control. They used the results as the basis for another experiment. Susan joined Phillip and Greg for the final experiment. Here, a control was present and replicated four times. They used the experiment as the basis for their inquiry lesson. Table 10 shows a summary of these experiments.

Table 10

A Comparison of Phillip, Greg & Richard's* Experiments Over Time

Experiment	**Question**	**Control**	**Operational Definitions**	**Sample Size & Replicates**	**Conclusions**
First	1 stated but too open ended for a testable hypothesis	None	Clearly defined "contaminate"	5 plates with many organisms in each, each plate with a different treatment	None stated or implied, did record their wish to replicate the experiment with better control
Second	1 clearly stated	None	Clearly defined "growth form"	6 plates with 10 spores each	Reported percentages and ratios of two different growth forms
Final*	1 clearly stated	Present and replicated 4 times	Clearly defined "germination," "pH" and "region measured"	16 plants total, 4 in each of 3 experimental groups and 4 control replicates	Reported differences based on comparison of experimental groups with each other and with control group

*[Note: Richard left the group and Susan joined by the time of the final experiment]

<u>Additional notes on student performance.</u> It should be noted, for purposes of fair presentation of data and results, that the students completed more than four experiments per group during the course of their enrollment in the "Just Do It" course. Also, some students pursued individual experiments in conjunction with their group experiments. One experiment, completed by Richard, will be examined in detail because it is incongruent with the general trend in improvement of experiments over time, detailed above.

During the course of his group's second experiment (see Table 10) Richard completed an individual experiment on the effect of light exposure on the growth rate of C-Fern™. He carefully detailed operational definitions for "light," "shade" and "partial shade" and monitored the growth of plants over time in each of these conditions. Richard designed an adequate experimental set up by covering one Petri dish partly, and another completely, with foil while leaving a third uncovered. He monitored the growth of the plants over the course of about four weeks and made detailed diagrams of the plants in his laboratory inscription notebook. However, Richard only used three plants in the entire study. Also, he made what he regarded to be valid conclusions that the plant was "shade loving" based solely on this unreplicated experiment with a minimal sample size. Richard went into great detail about his results and design during his group's presentation. Dr. Temple praised Richard's efforts as being a good example of an observational study in which he kept detailed diagrams. Richard did recognize and admit that his study was lacking in terms of replication and sample size.

> Richard: I'm at a stage now where I'm considering doing this whole experiment all over again but having additional plants rather than just three /// This is at least a start. [Eddie asks "You could call this a pilot study could you not?"]. That's correct.

Notice that even though Richard's individual study fell short of the ultimate course goals, his group's studies steadily increased in quality. Recall that he also noted the shortcoming of his lack of adequate sample size.

Finally, as part of the consideration of the quality of the final group experiments and their inquiry lessons, it is of note that Dr. Taylor had the following things to say.

> Dr. Taylor: I believe you all created your own lessons even though you used sources for some ideas. You dealt well with design flaws. You admitted them readily and discussed them. These are by far the best lessons we have seen from a group of students; no question in my mind.

Concluding Remarks On Results

The above section of this research report has dealt with evidence related to the fourth research question posed in Figure 11: Will participation in an inquiry-based science course, and in the activity of recording inscriptions, improve students' ability to design and carry out successful science experiments over time?

This chapter has presented the results of this research project which are most pertinent to the four research questions stated in Figure 11. The four research questions have been repeated in the current chapter and serve as a basis for the four primary section divisions of this chapter. Shared pedagogical and affective experiences pertaining to inquiry and assessment have been reported and discussed. Examples of inscriptions prepared by the students in the research study have been presented and discussed. Participants' reports about the effect of participating in inquiry and maintaining a laboratory inscription notebook on their ability to design and carry out successful experiments over time have been communicated, along with examples of changes in the efficacy of their experiments over time. In the next chapter, Chapter Five, the results of this research report will be discussed and conclusions will be made.

Chapter Five: Discussion and Conclusions

Overview

This research project deals with a qualitative analysis of a group of preservice science teachers who were engaged in learning science through inquiry and who were assessed, partly, by way of the scientific inscriptions they generated. The introductory chapter of this research report, Chapter One, briefly described the need for additional research on the topics of alternative pedagogical and assessment practices in science education. Four research questions were also listed in Chapter One. Chapter Two, Review of Literature, provided a review of major aspects of the scientific, educational and research literature most pertinent to this study. Specifically, the author's theoretical paradigm, social constructivism, was described. Its ties to professional science and to science education were also detailed. The notion of how scientific inquiry may be used as a pedagogical practice was also described in Chapter Two, along with past efforts to assess students engaged in inquiry. Finally, scientific inscriptions, and the related research of social scientists, were introduced in a historical account. This led to a discussion of the potential role of scientific inscriptions as valuable assessment tools in science education.

The methods of this research project were described in Chapter Three. Long interviews, focus groups and participant observation were described in general terms as research methodologies. The specific ways in which the author used these research methods to gather data for this research report were detailed. Finally, a description of how the author analyzed data collected for this project was offered. Chapter Four, Results, presented the data as they related to the four research questions. Numerous artifacts, transcripts of conversations and supporting examples were used to illustrate how the data helped to answer the research questions. In the current chapter, Chapter Five, the results of this research project will be considered in terms of their overall efficacy. They will be considered in terms of how they relate to pedagogy and assessment in science education specifically. Finally, remaining questions and suggestions for future research projects will be listed.

Efficacy of This Research Project

The efficacy of this research project will be considered in terms of two issues. These issues are validity of the study and reliability of the study.

Validity of This Research Project

Validity of any research project is addressed by the following question. "Does the research measure, describe or document what it is intended to measure, describe or document?" Qualitative research methods are known for their heavy emphasis on the actual words, actions and other communications provided by members of the research population. Therefore, most qualitative research studies are regarded as being highly valid (Singletary, 1993). This research project has utilized two primary methods of data collection. These methods are participant observation and interviews with the research participants. The authors' goal in reporting the results of this study (see Chapter Four, Results) was to allow the participants to tell their own story to the greatest extent possible. There has been a heavy emphasis on reporting the participants' words, artifacts, opinions and actions. Therefore the author has provided minimal bracketing or reduction (Denzin, 1989) of the participants' language and activities during the analysis of results. Bracketing involves the isolation of pure, basic themes from research data. When the author used bracketing or reduction, the participants had multiple opportunities to comment on the accuracy of these tentative interpretations. Jorgensen (1989) recommended this procedure for interpreting results from a qualitative study utilizing participant observation. When the participants' expressed concern regarding the accuracy of tentative interpretations, their concerns were addressed and included in the analysis. In general terms, then, the author claims a high level of validity for the present study. Specific issues regarding validity are detailed below.

The author provided operational definitions regarding important claims of cause and effect from this study. This method is recommended by both Fortner & Christians (1989) and by Yin (1994) to increase the internal validity of any study. Also, the author utilized seven specific sources of data. The use of multiple data sources is known as triangulation and further serves to increase the validity of a study (Patton, 1990). Only the notion of external validity is seen as problematic by the author. External validity focuses on the issue of whether one's research and conclusions may be generalized to other populations (Fortner & Christians, 1989; Yin, 1994). Because the size of the research population was so small (n=10), the author is reluctant to claim a high degree of relative external validity. The participants came from varying backgrounds, were of varying ages and had extensive training in the sciences, particularly the biological sciences, prior to the beginning of this research project. The author will only report that the issue of external validity may be of interest for further research. In other words, future researchers may wish to consider how the results of this study may be useful to similar or different populations of students. Researchers may best do this, in the opinion of the author, by adapting the methods of this study to other research populations of interest. This issue will be further considered at a later point in the present chapter.

Reliability of This Research Project

Reliability of any research project, according to Yin (1994) is addressed by the following question. "Can a study be repeated with identical or very similar results?" The issue of reliability regarding most qualitative research projects may be problematic. McCracken (1988) noted that there is a tendency to judge qualitative research projects by way of those standards commonly used to judge traditional quantitative research. The author's background and biases as a qualitative researcher were listed and addressed in Chapter One of this study. Bogdan and Bilken (1997) stated that two qualitative researchers may very well arrive at two different sets of conclusions during the course of a research project. Qualitative methods generally do not claim to allow for the complete removal the researcher's background and biases from the research and processes (McCracken, 1988). The author makes no claim of high reliability for this study. This is consistent with the expected decrease in relative reliability for most qualitative research studies (Jorgensen, 1989; Singletary, 1993).

Discussion of Results

This section will present a discussion of the results obtained from this research project. Table 11 presents an overview of these results. Each discussion point identified in the table will be described in detail in separate subsections of the text.

Student Preparation in the Sciences

The research participants in this study all had very noteworthy academic backgrounds in the sciences, particularly the biological sciences. Most of the students in this study held Bachelor's degrees in either general biology or in a more specific field, such as zoology, within the biological sciences. Some students had professional work experiences within the sciences as well.

Table 11

Summary of Discussion of Results

Discussion Point	Elaboration
Student preparation in the sciences	Students appeared to be poorly prepared regarding the Process and Nature of Science Domains.
Students' experiences with inquiry	The experiences fostered and promoted an understanding of Process and Nature of Science Domains of science education. These experiences also allowed the students to participate in a scientific apprenticeship while learning.
Students' experiences with authentic assessment	Numerous types of authentic assessment techniques were used successfully to evaluate the students. The students used words such as "real" and "genuine" to describe these assessment techniques.
Students' experiences with inscriptions	Many types and examples of scientific inscriptions were created, understood and used by the students. Students benefited from the rubric used to evaluate their inscriptions and from explicit instruction about how professional scientists create and use inscriptions.
Student change over time	Experiments performed by the students improved over time. Students reported that the practices of actually doing experiments and recording inscriptions fostered this improvement.

However, none of the students had first-hand experiences with actual scientific research (see Table 1).

Several instances were described in this report in which the research participants displayed behaviors that were very uncharacteristic of, and unanticipated from, a biology major or any other well prepared science student, even at the undergraduate level. Some students were unable to correctly use a microscope, arguably the most basic tool of a biologist. Also of note is the fact that the research participants were apparently mystified by their observations of mealworm cultures (see Table 3). Some of the participants believed that their pupated mealworms were dead. Some asked questions about whether metamorphosis was occurring within their cultures. The concept of metamorphosis, it should be noted, is regarded as an appropriate topic of study for students as early as the elementary grades (NRC, 1996; NSTA, 1996; NRC, 2000).

Of further note is the fact that all students failed in their earliest attempts to design and carry out a simple experiment when given basic materials and supplies. Referring to Tables 7, 8, 9 and 10, one can see that none of the students had a clearly stated, testable question for their first investigations. Only one student group had a control and no useful conclusions were generated from any of the initial experiments.

All of these findings suggest that the students came to the "Knowing and Teaching Science: Just Do It" course with little to no quality understanding of what Enger and Yager (1998) have called the Process Domain and Nature of Science Domain of scientific learning. These domains focus on how scientists do their work and how they evaluate evidence. The students in this research study were able to verbalize a fairly well articulated notion of the "scientific method" and of an "experiment" but they initially failed to demonstrate their ability to actually apply this notion in a genuine, authentic context. This suggests that the concepts inherent in the Process Domain and Nature of Science Domain of science (Enger & Yager, 1998) were not embodied in the participants prior to their enrollment in the "Just Do It" course. The students, themselves, often contrasted their previous laboratory experiences with those had in the "Just Do It" course. They used words like "cookie cutter" and "cook book" and "recipe" to describe their former laboratory experiences. The students often spoke of how the "Just Do It" experience was different from these previous experiences and how it helped them better understand processes and skills involved in actual scientific practice. All of this further provides support for the continuing calls for students at all levels of education to be exposed to experiences, like scientific inquiry, that facilitate development of the process skills of science (AAAS, 1990; NRC, 1996; NSTA, 1996; NRC, 2000). The science education community should continue efforts to expand students' exposure to inquiry-based experiences at all levels of education.

Student Experiences With Inquiry

The research participants had extensive experiences with inquiry during this study. The students worked with real scientific questions by designing and carrying out actual experiments and considering results. They utilized a variety of laboratory materials and equipment and consulted published references during the process of honing their experiments and considering their results.

All of these characteristics are consistent with descriptions of inquiry (Roth, 1995; German & Aram, 1996; NRC, 2000; Zachos, et al., 2000). Further, these experiences and teaching methodologies are in accord with various recommendations for reform in science teaching (AAAS, 1990; NRC, 1996; NRC, 2000). The students also worked collaboratively, to negotiate meaning and combine their efforts, consistent with the recommendations of other researchers regarding the use of inquiry in classrooms (Bowen & Roth, 2000). Roth (1995) called the power of a group of students to do more than the individuals could do alone "scaffolding." Students in this research study frequently spoke of, and wrote about, how important their collaboration was in the course. In following the analogy, students together built a scaffold upon which they could climb higher than they could have climbed alone. This heavy emphasis on the collaborative construction of knowledge is the very essence of the social constructivist view of education (Blumenfelt, et al., 1996; Baker & Piburn, 1997; Staver, 1998; Glassman, 2001).

The results of this study also showed that the students learned a wide variety of science content during their inquiry activities in the "Just Do It" course. They studied several basic biological concepts such as metamorphosis, genetics, life cycles of organisms, environmental biology and others. Further, they studied a few basic chemical concepts including pH, preparation of solutions, chemical signals in living organisms and other ideas. The students performed calculations, prepared graphs and tables and calculated ratios, percentages and rates based on their own laboratory data. The multitude of quality experiences had by the adult research participants in this study are in accord with the findings of other researchers that inquiry can improve content knowledge, process of science skills, reading and math skills of students from elementary to high school grades and beyond (Shymansky, et al., 1990; Boujaoude, 1995; Hurd, 1998). NRC (2000) also notes that inquiry may foster a deep understanding of such basic concepts as those encountered during the "Just Do It' course, and AAAS (1990) verifies that math skills are practiced in a more meaningful context during scientific inquiry.

Another interesting feature regarding the students' experiences with inquiry during this research project is also worthy of note. The students verified that they were part of an apprentice-type learning environment regarding their relationship with the course instructors, particularly with Dr. Temple, the professional research scientist and Botany/Genetics professor who taught a portion of the course. This aspect of the "Just Do It" course brings an even more authentic component of the experience to light when considered in terms of other studies of the sociology of science. Several authors have repeatedly verified that professional scientists operate within social groups and that the master-apprentice relationship typifies the acculturation of novices into the community of practice (Latour & Woolgar, 1979; Garfinkel, et al., 1981; Latour, 1987; Lave & Wenger, 1991; Roth, 1995; Barnes & Bloor, 1996; Roth, et al., 1998; Knorr-Cetina, 1999; Bowen & Roth, 2000; Barab & Hay, 2001); Buxton, 2001. Other writers have noted that such an apprenticeship experience may be readily replicated in the science classroom, at various levels of education (Ritchie & Rigano, 1996; Buxton, 2001; Melear, et al., 2000; Bowen & Roth, 2000; Wilson & Lucy, 2002).

Student Experiences With Authentic Assessment

Students enrolled in the "Just Do It" course were evaluated by a variety of formative and summative methods regarding their course experiences. For example, the students were required to informally defend their conclusions and claims to the course instructors (see Tables 4, 6, and Chapter Four). They were required to write formal research papers, present oral summaries of their work, evaluate each other's work and to maintain reflective and inscription journals. These evaluation techniques are called authentic because they relate concretely and directly (Enger & Yager, 1998) to the learning and inquiry experiences described in the previous subsection. They are also consistent with things an actual scientist may be called upon to do during the course of his or her work. Specifically, the students worked with real scientific questions, designed and executed their own experiments, consulted published scientific references and used laboratory equipment. The students agreed that the assessments used seemed more genuine and real than the traditional paper and pencil tests they had so often encountered in other science courses. It is also of note that assessment, occurred on an ongoing basis, consistent with various recommendations and research reviews (Perkins & Blythe, 1994; NSTA, 1996; Ochanji, 2000). The evaluation methods used in the "Just Do It" course were largely typical of the sorts of things that professional scientists would do in order to defend their work among members of their community of practice. Students wrote formal research papers and made presentations based on their experiments, they evaluated their own work and the work of their peers, they kept reflective journals and made inscriptions (see Figure 20).

Student Experiences With Inscriptions

The participants in this research project produced hundreds of scientific inscriptions based on their inquiry experiences and collaborative efforts. The inscriptions were varied and ranged from written statements (see Figures 25 and 26) to diagrams (Figures 27 through 30) to data tables, graphs and equations (Figures 31 through 38). The students reported that they enjoyed preparing the inscriptions and that the activity of recording inscriptions helped them to better consider, plan and carry out successful experiments.

There is ample evidence that the inscriptions prepared by the students fostered "science talk" and negotiation of meaning among the participants, the instructors and teacher assistants. This fact supports contentions made by previous researchers concerning the power of student-made inscriptions to guide scientific sense making and move individual mental representations into a social arena (Roth, 1995; Roth & McGinn, 1998; Barnett, et al., 2001). Also, it is again of note that practices such as these are consistent with the social construction of knowledge (Blumenfelt, et al., 1996; Baker & Piburn, 1997; Staver, 1998; Glassman, 2001).

Students routinely shared inscriptions within and among their cooperative work groups (see Figure 37 for one example) and were often involved in whole-class discussions of evidence as an inscription began not only to take shape but also to guide the content of the discussion and discourse. Table 6 provides an example. Roth (1995) has used the term "conscription" to refer to inscriptions that take on this level of social magnitude. The term conscription is derived from the Latin roots "com" meaning with and "scribere" meaning write. One older use of the term conscription was applied as a group of individuals were enrolled into military service as their names were written down. Using this analogy, it is easy to imagine the participants in this study being drafted or compelled into service by the emerging group-made inscription described in Table 6. In other words, the inscription pulled the class toward it and the students were deeply involved in its completion and negotiation of its meaning.

One other aspect of the students' experiences with inscriptions is worthy of detailed consideration. The students received explicit instruction at the beginning of the course concerning what scientific inscriptions are and how they are generated and used by professional scientists. Also, the students maintained a laboratory inscription notebook, which was evaluated using the rubric shown in Figure 9. This rubric was prepared with the uses of inscriptions by professional scientists in mind (Roth & McGinn, 1998) and included such criteria as improvement in inscriptions over time, social use of inscriptions and transformation of inscriptions from simpler to more abstract forms. In their study of student experiences with inscriptions, Barnett, et al. (2001) concluded that students in their research study failed to fully understand and appreciate the complexity of information depicted in inscriptions the students themselves generated. This study suggests otherwise. There is ample evidence that the students understood that an ultimate graphical inscription, for example, represented and came from data points they collected, tallied and recorded. In other words, the students appeared to acknowledge and appreciate that the inscriptions they made were a mirror of their research, no matter how abstract the inscriptions were. They used the inscriptions to prepare oral and written research reports. They used inscriptions to facilitate discussion and often referred to trends, results and conclusions supported by their inscriptions. Students further agreed that the rubric (Figure 9) and explicit instruction about inscriptions helped them generate better inscriptions and do better science over time. They agreed that the rubric (Figure 9) served as a sort of blueprint or organizer. The rubric and explicit instruction may well have made the difference in allowing the participants from this study to fully appreciate and understand the power of a well-prepared inscription. Perhaps the rubric and explicit instruction served as what Feuerstein, et al. (1979) called an "instrumental enrichment" and what Greenberg (2000) called a "cognitive enrichment building block or tool." In other words, the rubric and explicit instruction about inscriptions may have provided the participants with a metacognitive advantage, which helped them to maximize the experience and fully understand inscriptions.

Student Change Over Time

One of the research questions of this study involved a consideration of the effect of engaging in inquiry activities and in recording scientific inscriptions on the participants' ability to design and carry out successful experiments over time. The students overwhelmingly reported that this was the case. The students' actual performance over time is reported in Tables 7 through 10.

This research question, concerning the effect of participating in inquiry and recording inscriptions on the ability to design and carry out successful experiments over time, is probably the most problematic question of this research project in terms of discussion. Tables 7 through 10 do demonstrate improvement in all student work group experiments over time. It is assumed that this improvement was at least influenced by the practice of engaging in inquiry and recording inscriptions. The improvement was not stellar but improvement did occur. The participants seemed to become more adept at identifying, managing and reporting problems with their experimental designs with the passage of time. Some experiments, particularly the last two experiments carried out by Ralph and Morgan, had a very sound scientific basis in terms of sample size and control (see Table 8).

Implications For Future Research

The results of this research study clearly suggest that there is a need to continue considering the potential roles that inquiry and inscriptions (especially in combination and including explicit metacognitive coaching and instruction about inscriptions) may have at all levels of science education. This study focused on only one group of graduate students who were all preservice secondary science teachers. It appears that pedagogical and assessment techniques such as those utilized so heavily in this study could be typical of the sorts of things that are missing from most science curricula today. Additional studies concerning the experiences of graduate and undergraduate college science majors of various disciplines, of non-science majors, of high school students and of elementary students who are actively engaged in long-term inquiry activities and in recording scientific inscriptions could help to clarify and generalize the findings of this study.

Eiriksson (1997) reported that preservice elementary science teachers had deeply held resistance concerning the practicality of teaching by inquiry. It would be interesting to see if participation in an experience similar to the one detailed in this research report would help to alleviate those concerns and provide an effective model for teaching by inquiry and assessing through authentic means. All of the participants in this research study reported to the author that they planned to utilize inquiry and/or authentic assessment techniques such as inscriptions in their own classrooms in future years. Therefore, it will be critical to the final evaluation of the "Just Do It" course to know if these participants actually do transfer concepts and skills from the course to their own classroom teaching. In more general terms, the participants' own (and their students') future experiences, perceptions, outcomes and actual uses of inquiry-based instruction and authentic assessment need to be documented carefully as well.

General Chapter Summary

This final chapter, Chapter Five, of this research report has considered the study at hand in terms of its validity and reliability. Further, a discussion of general themes from the study has been offered. Some suggestions for future research have been described as well.

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Appendix

List Of Symbols and Abbreviations

SYMBOL OR ABBREVIATION	CLARIFYING COMMENTS
°C	Degrees Celsius
ST	Salt Tolerant
TM	Trade Mark
WT	Wild Type
&	and
...	A portion of a direct quotation has been removed
///	A speaker briefly pauses or hesitates
>>>	Another person interrupts a speaker
[ ]	Material inside brackets is added for clarity
___	A blank (___) is used to indicate that material has been omitted to protect participant confidentiality
%	Percentage, percent

Table 6

Discussion of Sperm Migration & Sporophyte (continued on next page)

AUDIO TRACK	VIDEO TRACK
1. Susan: Well (inaudible) The larger one is the sporophyte?	Dr. Temple begins to engage Basma, Sara & Susan in conversation. They have used the word "sporophyte" in their conversation with him.
2. Dr. Temple: So what can you deduce from that, & then test? So, if you're right ///	
3. Susan: It might be a sporophyte>>>	
4. Dr. Temple: That's in the future, where did it come from?	
5. Susan: Well it didn't come from the rice, the rice>>>	
6. Dr. Temple: Ok, so it didn't come from the rice. Can you show that, can you prove that?	
7. Basma: I think our rice are turning into corn flakes, too.	
8. Dr. Temple: Yea, there's more complexity.	
9. Susan: Yea, but the rice are actually surrounding the corn flakes.	
10. Dr. Temple: Could you actually do an experiment to show that? Could we do a "thought" experiment? How would you do a thought experiment to demonstrate what you just said? This new thing you're calling a sporophyte came from the rice.	
11. Susan: We /// we take a corn flake & put it on here & put a rice here. This is actually to see if rice became corn flakes or if corn flakes became rice. This one would be just corn flakes. This would be our control. This would be rice & corn flakes on the same plate.	Points to a Petri dish.
12. Dr. Temple: Did it make a difference? On your just corn flakes or just rices /// Are they the same?	
13. Basma: No.	Basma opens a Petri dish & shows it to the group.
14. Susan: Just the corn flakes appears to have the organism on it>>>	
15. Dr. Temple: So now you're calling it an organism?	
16. Dr. Temple: Yea, hairs on the root, what'd you call that?	Points to a Petri dish.
17. Sara: A root hair?	
18. Dr. Temple: A root hair yea.	
19. So how would you demonstrate /// If somebody came by & said "you're full of it, those things are just big corn flakes." How could you say that it's a sporophyte /// that's what you called it? You say "Eureka, I've discovered how these things turn into sporophytes." How would you demonstrate that? That's the tricky part.	Basma opens a Petri dish.
20. Susan: You're so good at this!	Laughter from all.
21. Dr. Temple: I'm not any better at it than you are.	
22. Basma: The shape has changed! It's was kind of a little /// a heart shape, & if you look at it its not a heart shape anymore.	Basma points to the topic of the conversation in the Petri dish.
23. Dr. Temple: You can make a lot of observations about this & that would be part of it. But you still have the question where it came from.	
24. Where do you think it came from?	
25. Susan: Oh, I think it came from the corn flake producing gametes /// ah /// they came together & made the sporophyte.	Laughter from all.
26. Dr. Temple: So, what kind of gametes?	
27. Susan: Those little spiral, swimmy things?	
28. Dr. Temple: Well, with your deep knowledge of biology, what would you think?	
29. Susan: That there ought to be two different ones.	Laughter from Susan.
30. Dr. Temple: So what do you think?	Basma looks at the Petri dish.
31. Susan: I don't know if you would have two different ones or not.	
32. Dr. Temple: Do you think one option would be the two spirals coming together?	Speaks too all three.
33. Susan: Well, we definitely have the spirals coming from the rice.	
34. Sara: The spirals come from the rice.	
35. Basma: We even stained it.	
36. Sara: How could we test that?	
37. Dr. Temple: So, if you noticed that, they were swarming in & congregating, what would you deduce from that? See /// you get this huge question /// it can be hard to dissect it /// but if you go through like a bunch of 'what ifs' you'll eventually come to something that's more distinct & testable. It's hard to test this big question /// So, why would they be congregating? Hum?	Motions with hands Susan nods her head "no" toward Dr. Temple.

Table 6 (continued on next page)

AUDIO TRACK	VIDEO TRACK
38. If they are congregating, what would they be there for?	
39. Sara: They're looking for an /// egg>>>	
40. Dr. Temple: An egg /// So where would you then deduce the egg is? Assuming the spirals are looking for the egg, do you think they'd be better at it than you would?	All three students remain silent.
41. Susan: I think it might be somewhere else.	Susan opens lab inscription notebook. Points to an inscription.
42. Dr. Temple: So how could you determine that?	
43. Dr. Temple: One way is to look /// Your stains>>>	Speaks to Sara.
44. Sara: We did look & it depends on ///it depends on how old the corn flake is whether it stains /// with the younger corn flake we didn't get a thing.	
45. Dr. Temple: Ah, assuming the spirals are looking for the egg, do you think they'd be better at it than you?	All three students remain silent.
46. Sara: Yea.	
47. Dr. Temple: So how could you maybe think of a way to let the spirals tell you where the egg is?	
48. Dr. Temple: Think about that for awhile. Because at that point you can sort of say "Well I propose that the sporophyte bla bla bla the egg is in the corn flake /// the spirals are searching for the egg." If you can then document that that kind of mating occurred then /// well you've basically not demonstrated it.	Sara nods her head "yes."
49. Dr. Temple: You could show that it is attracting it there. Or you may look & find that the spirals just sort of get together by themselves.	
50. Susan: Well I don't believe the spirals are getting together on their own because basically you wouldn't have the organism growing anywhere. And they're definitely growing out of the corn flake. So they're definitely not.>>>	Points to Petri dish.
51. Dr. Temple: So, that's a very good thing you just put together. Presumably, if you had just two spirals coming together you could just watch that on the plate. & the other way...[inaudible] See if you can get some idea of what's happening.	
52. Basma: So in other words, we just have to be curious George. Asking, asking, asking.	
53. Dr. Temple: Well, we all do this. Most of the questions we ask are big questions. The scientific thing is dissecting them small enough. Ask "How am I going to deal with that? " So you might want to even /// Where are your spores? Well, I'll give you a hint. It's getting so much material growing on it that those things are going to run out of nutrients. So I'll give you a suggestion. I've got some drink bottles upstairs that you can put some soil mix in. I'll get some of those.	Another group calls for Dr. Temple's assistance as Basma begins writing in her lab notebook & Sara & Susan begin looking in the dissection microscope. The other group begins talking about another discovery they have named "Jimmy Durante."
54. Dr. Temple: So what is the Jimmy Durante?	
55. Richard: It comes from between the two corn flakes. It has the little clump of those things we call the fiber optics going out & ///	Richard holds his hands up to form a trough. He looks in lab notebook and gestures again.
56. It falls over on its back, so to speak & right there's where it grows out of.	
57. Dr. Temple: What is it?	
58. Richard: I think that's going to be the>>>	
59. Greg: Final result.	
60. Richard: Yea, the beginning of the final.	
61. Greg: The beginning of the final stage of it.	
62. Dr. Temple: Is it a corn flake or is it something separate?	

Table 6 (continued on next page)

AUDIO TRACK	VIDEO TRACK
63. Richard: Well, I mean it came from the corn flake.	
64. Dr. Temple: That could be a hypothesis. You're hypothesizing that it came from the corn flake. So at this point you've got some good observations. Can you demonstrate that?	
65. Phillip: The coils they would>>>	Phillip looks toward Richard & gestures with his fingers.
66. Richard: Yea, from the rice. They would come out of there & then on the corn flake, they would go all over the surface. The ones that we saw they were going along those canals. They were ///	Richard looks toward chalkboard & leaves his chair.
67. Richard: Now these little canals were all along the surface of the corn flake. There was no pigmentation at all in these little canals.	Begins drawing on the board. Completes drawing, then turns toward his group & Dr. Temple.
68. Richard: There was green all around here ///	
69. but these were completely transparent.	Points to diagram he just drew.
70. Richard: The coil would come along & it would go right in these canals. It would come right along & then continue down the surface.	Colors a section of the diagram & points at it. Gestures & moves chalk in a spiral motion.
71. Richard: And the rice>>>	Begins drawing again.
72. Susan: How did you see that?	Richard turns toward the class.
73. Dr. Temple: My next question is do your colleagues agree? Has anybody else seen that?	
74. Sara: You're saying the spirals go through the canals?	
75. Richard: The spirals go along the surface of the corn flake. That's what I observed in every single one that I saw. Where the /// where we had movement along the top of the corn flake.	
76. Sara: Were you just watching under magnification under the microscope?	Richard nods his head "yes."
77. Richard: Umhum.	
78. And then the coils all seem to be like in the rice, they seemed to be like a /// like basket like structures that all of the coils are in.	Richard begins to draw.
79. Sara: Umhum.	Richard speaks to entire class.
80. Richard: Would you all agree with that?	
81. Susan: We saw like some of the>>>	
82. Richard: We had a slide. Then I looked at one that Ralph & Morgan had & that's just what I observed. Just the white out area on the corn flake. That's where the coils would move all along the surface there.	Turns toward his diagram on chalkboard.
83. Dr. Temple: So you guys haven't seen that? This is like Martians everywhere.	
84. Susan: We saw /// I saw them moving around but I didn't see anything like a real order.	Richard returns to his workstation.
85. Phillip: I seen the canals.	
86. (Inaudible discussion, several students speaking at once)	
87. Dr. Temple: So what do you think your canals could be?	
88. Susan: Well, I'm not saying they're not there. I just haven't observed them.	
89. Dr. Temple: Oh, so you're convinced they're there.	Dr. Temple speaks to Richard.
90. Susan: No, I'm not necessarily convinced they're there. I'll have to do another slide.	
91. Dr. Temple: Well, we could do that today, right?	
92. Susan: Yea.	
93. Dr. Temple: So, cavities & canals.	
94. Richard: So how would you test for DNA or something like that?	Speaks to ?
95. (Various inaudible conversations continue)	
96. Greg: Those little squiggles are traveling through something.	Greg beckons to Dr. Temple.
97. Dr. Temple: You said they were going to that. How would you demonstrate they were going to some visible spot?	

Table 6 (continued on next page)

AUDIO TRACK	VIDEO TRACK
98. Greg: I think you'd (inaudible)	Various conversations make this exchange largely inaudible.
99. Dr. Temple: If you do that kind of experiment, you'd want to use the higher power.	Dr. Temple speaks to Greg. Richard motions to Sara to come to his workstation. Sara approaches Richard's workstation & looks in the eyepiece of microscope.
100. Richard: Right there where the pointer is, those things that are coming out. That's a corn flake right there & if you look real, real close, the canals are not as defined on that one as on the one that I observed earlier. 101. Can you see the white out area? 102. Sara: Yes.	By now Alice, Phillip & Veronica have crowded around Richard's workstation.
103. Richard: Around there. If you look close enough you can tell that they're staying mainly on the little /// 104. Richard: See where the pointer is? They're mostly right there, the spirals.	Alice looks in microscope.
105. Alice: Yea. 106. Richard: The little canals I guess just aren't as defined.	Veronica looks in microscope.
107. Eddie: Did you say you found another one of the situations you drew on the board?	Eddie speaks to Richard.
108. Richard: This one right here? 109. Eddie: With the canals?	Richard points to his diagram on chalkboard.
110. Richard: Yea. The one that I observed earlier was more like this. The ones in that slide are more like this.	Richard is off camera but apparently is drawing on the chalkboard. Several inaudible conversations going on. Eddie & Richard continue conversation; other students look in Richard's microscope & discuss things with Dr. Temple & with each other.
111. Susan: They look kind of random to me.	
112. Richard: See where that pointer is? 113. Phillip: Yea, they're definitely like>>>	Phillip looks up from microscope at Richard.
114. Richard: They pop out of that right there. They're just like /// 115. I was just sitting there watching & they were coming out like that.	Richard makes a gesture with his hands like an explosion.
116. Eddie: Was that particular one grown in a dish just by itself or with other corn flakes?	Richard looks at lab notebook & remains silent for about one minute.
117. Richard: This was /// This was from this ///	Richard brings Petri dish to Eddie.
118. It was grown with others.	Greg looks into eyepiece of microscope for about 15 seconds.
119. Greg: Some of them are going all over. That's kind of cool.	Off camera, Richard prepares another slide.
120. Dr. Temple: So, does he have special hands or what?	Speaks to entire class Richard laughs

Table 6 (continued on next page)

AUDIO TRACK	VIDEO TRACK
121. Sara: I don't know.	
122. Greg: So what did you do?	
123. Richard: I took it out & put it on a slide.	
124. Sara: I see the canals in ours but I don't see any spirals.	
125. Richard: You don't see any spirals in that one? I'm trying to find it on this one.	
126. Dr. Temple: You see canals in that one?	Dr. Temple speaks to Sara.
127. Sara: Yea, I see canals.	
128. Dr. Temple: Do you think that /// the canals are /// (inaudible)	
129. Greg: The areas that don't have the pigment. And there's some that just seem to go across the whole thing. I wonder if maybe they're outside or>>>	Greg speaks to Phillip.
130. Susan: So you have to watch one /// at a time?	Susan speaks to Greg.
131. Greg: Yea.	
132. Eddie: So you all found the canals that Richard drew on the board. Is that right? But you've not seen the motion?	
133. Sara: Not yet.	
134. Eddie: Did you do something different as far as how your specimens were>>>	Eddie speaks to Sara & points to chalkboard.
135. Susan: No. He took it from our plate.	
136. Eddie: Really? Neat. That don't make a lot of sense.	Greg points to his microscope.
137. Sara: So Richard, you're actually seeing the spirals swimming through the canals?	Eddie, Sara & Susan move toward the microscope. Eddie looks in eyepiece.
138. Greg: Yea look at this. This is a good slide.	
139. Richard: Yea.	
140. Dr. Temple: I think /// I want you to rectify the ///I mean you've got	
141. Greg: Well, yea. We're going to go back.	
142. Dr. Temple: Susan doesn't believe in canals. And Richard really believes in them. Some other people are skeptical.	
143. Richard: Now the ones in that one are not like the ones I drew on the board. The ones in that one are much more /// They're not anywhere near as broad. That's why I'm trying to find this one on this slide.	
144. Dr. Temple: There's a resolution to that conflict. You should not leave here today without resolving it.	
145. Susan: Really?	
146. Alice: We see the lines separating them. We don't see any spirals.	
147. Eddie: What magnification are you on?	Eddie turns toward Greg.
148. Greg: Oh look guys. I just saw one go in there & its going nuts.	Sara looks into Greg's microscope.
149. Dr. Temple: So how do these things get around.	
150. Phillip: They shuffle /// yea.	Eddie looks into Richard's microscope. *Note: It is at this point that the author recognizes the "canals" as the developing vascular system. According to reflective notes & recollections, Eddie decides not to interfere with the on-going discussion. Eddie even told some students he saw the sperm cells swimming in the canals.*
151. Greg: Look in the middle. /// Ok, here's another one.	
152. Richard: Ok look at this slide right here & you can see it. This is a slide that we did. I mean this is our first wet mount. You can see the white out areas a lot, lot better.	
153. Alice: Are these from sterilized?	
154. Eddie: Ah. Yea, I see what you mean.	
155. Dr. Temple: So when you looked at the little, you used the term mitt or glove stage, they're perfectly flat, right?	Several inaudible conversations continue. Dr. Temple continues the discussion with Richard and others.
156. Richard: They appear to be.	
157. Dr. Temple: You're being very careful.	Laughter from several.

Table 6 (continued on next page)

AUDIO TRACK	VIDEO TRACK
158. Dr. Temple: So at this stage, you're saying that they're not flat anymore, that they have canals?	
159. Richard: I called them canals just because that's, just terminology. That's what I noticed the spirals were staying on. And plus, they're different because there's no pigmentation in them and /// if you'll look right there.	Greg looks into Richard's microscope.
160. Richard: Look right there.	
161. Richard: See the white out areas?	Richard speaks to Dr. Temple.
162. Dr. Temple: Yea. This is at a very high magnification.	
163. (Various inaudible conversations)	
164. Dr. Temple: Well, the little spirals are almost /// could you pick out more one or two going side by side through those little canals? And you don't exclusively see them in the canals?	Dr. Temple looks into eyepiece. Greg & Richard shake their
165. Greg & Richard: No.	heads "no."
166. Dr. Temple: So you're telling me that sometimes you see them in the canals & sometimes they are not in the canals. So, do they need to move in the canals or ///?	Dr. Temple speaks to entire class.
167. Susan: I think that what they're thinking is they need to get in the canals to get where they're going.	
168. Dr. Temple: Oh. Ok.	
169. Susan: To get where they really want to be.	
170. Dr. Temple: The canals look like a network don't they? Am I right Richard? Is the canal a big network?	Richard gestures with fingers.
171. Richard: Uhum.	Richard gets up from chair
172. Dr. Temple: So is it like one of those maze puzzles you see?	and approaches the chalkboard. He draws a series of hexagons that touch
173. Richard: It's almost like a honeycomb pattern. You know how a honeycomb pattern is? It has almost a hexagonal shape & all of them fit together. You take ///	one another. Richard points to diagram. Richard shrugs his shoulders.
174. & then in between ///	
175. those are the canals that run. In there is what I was mentioning a couple of weeks ago about it looking like little green dots which could be chlorophyll or ///	Richard erases previous sketch as well as another area on the board & begins drawing a new, larger &
176. But that's on a much higher magnification that you can see that.	more detailed, diagram.
177. Dr. Temple: So why don't you just draw those two things on a larger mag right up there but including your chloroplasts.	Various inaudible conversations continue for about five minutes as Richard draws.
178. Richard: Did you see the little round spots on here? That's what I first pointed to.	Eventually Eddie and Richard stand near the
179. Eddie: Near the notch?	microscope, Eddie looks into eyepiece.
180. Richard: They're like on the edge. I've got the pointer on one right now. There's no activity around it right now.	Richard looks into eyepiece.
181. Eddie: Where the pointer is?	
182. Richard: And see how the channels are a lot more wide in that than they were in the other?	
183. Susan: Did you see any canals, Eddie?	
184. Eddie: Yea /// oh /// and he's got that slide toward the margin of the leaf-like structure & they're a little more pronounced so you may want to look. And I'm seeing what I think is random movement & then movement through the canals. (see *italics* above)	Susan walks toward Richard's microscope and looks into eyepiece.
185. Susan: Are you still on that spot?	About 10 minutes elapse. Various inaudible
186. Richard: They're just kind of randomly moving but occasionally they'll be one that ///	conversations.

Table 6 (continued on next page)

AUDIO TRACK	VIDEO TRACK
	Dr. Temple says something inaudible to Susan.
187. Eddie: It looks to me like it goes right through it.	
188. Richard: Do you see the little white out area I'm talking about? That little pattern, hexagonal area. It's just kind of right below it.	Susan goes to chalkboard & adds to Richard's drawing.
189. Susan: So you don't think that's just like the edge of the cell?	Susan points to one of Richard's drawings within the larger diagram.
190. Richard: Well, I don't know, that's what I'm>>>	
	Dr. Temple points to diagram and speaks (inaudibly) to Susan.
191. Susan: We need to resolve this canal question before we leave.	
192. Susan: Well, do you want me to do it right now?	Dr. Temple points to Richard, speaks to Susan.
193. Dr. Temple: Yea, yea, yea.	Susan laughs & then adds a few more details to the diagram.
194. Susan: Well the main thing that I saw was that there would be like, just like a cell somewhere that had /// And then all of these cells just had one /// 195. Dr. Temple: So these are cells? What are those? 196. Susan: What are the little things? 197. Dr. Temple: What are these spots? 198. Susan: Cell walls.	
199. Dr. Temple: Go argue that with him.	Points to Richard. About ten minutes elapse.
200. Susan: So Richard, what are you doing?	Sara & Susan approach Richard and Greg.
201. Greg: We're making twelve slides. Four with a corn flake & rice. Four with corn flake & rice. Four with two rice. We're trying to illustrate the fact that the squigs come from one & go directly to the other. 202. Sara: Are you guys doing a spiral experiment? 203. Susan: Have you all done any of the stains. 204. Richard: Nope. 205. Susan: You all might want to stain one of the corn flakes. Because those squigglys were all in there. 206. Sara: They contain DNA, that's how we proved that those squiggles>>> 207. Greg: But how does that prove that? 208. Susan: I think what it means is that the corn flake is like hermaphroditic & that it makes both. 209. Greg: How. You have to prove it. 210. Susan: Well if you look at it it's got some cells that have the squiggles in it. You see it in the stained slide. 211. Greg: So how do you know they didn't come from another rice to this one? 212. Susan: Well, it's a whole cell that's producing it. It's a whole cell that's just jam-packed with them. 213. Greg: How do you know its producing it? 214. Susan: Well /// 215. Greg: That's what I'm saying. If you say something like that /// He will want to know how we know. 216. Susan: Well, I mean it's not very likely that the little things all went into one cell. I guess it could happen but /// they're growing there. Don't you have your /// Eddie is that the corn flake? 217. Eddie: Umhum. 218. Susan: And don't you see, like every now & then there's a little pouch with squiggles. 219. Eddie: Yea, I see that & what I'm looking at right now, I've got it on the absolute lowest power. And /// this stain stains nucleic acids, right? Or is it specific for DNA?	

Table 6 (continued on next page)

AUDIO TRACK	VIDEO TRACK
220. Susan: No, just nucleic acids.	
221. Eddie: Those little canals, that Richard mentioned, are so clear. Did you see that? I mean you>>>	
222. Susan: No I didn't see that.	
223. Eddie: Well, I've got it on low power.	
224. Basma: Will you let me see?	Basma speaks to Eddie.
225. Eddie: Oh, yea. You see on the lower right hand, the lower jimmy durante thing ///	
226. Basma: Oh that, yea I see it.	
227. Eddie: It picked up a lot of that stain didn't it? I don't know that that means anything but /// Did you see how it picked up the stain? That just makes me wonder. Of course anything makes me wonder.	
228. Basma: That's why you're a scientist.	
229. Eddie: Ah. Maybe so /// I don't know.	Susan looks into eyepiece of
230. Eddie: You see what I mean, right?	microscope.
231. Susan: Yea. I do. Richard you want to look?	
232. Eddie: Sometimes it seems that when you go back to low power that you get a bigger picture view than you can get with>>>	
233. Susan: Yea, I wasn't seeing much on the high power.	
234. Eddie: You can see lots of nucleic acids but I really didn't see a pattern, other than the spiral thing. You said something about those didn't you?	
235. Susan: Yea, did you look at them?	
236. Eddie: Yea, I did. I did.	
237. Susan: I mean they're very clearly in there.	
238. Eddie: Yea, no doubt. No doubt. I saw that. But I just sort of wanted to pull back & see if I could see them in any kind of pattern.	
239. Has anybody tried to look at one of those spirals under oil immersion? That might be a neat thing to try.	
240. Richard: You can't keep it in frame long enough.	
241. Eddie: Oh really. Maybe if somebody can get into a whole big group on a real fresh slide, maybe Wednesday or next week, that might be a real neat thing to look at.	Eddie speaks to entire class. About three minutes elapse
242. Eddie: Have you all seen this yet? You may have to use the fine adjustment knob.	Eddie walks to microscope & speaks to Susan.
243. Susan: You can trace it all the way ///	Susan looks in eyepiece,
244. Eddie: Richard needs to see that one too don't he?	motions with her fingers to Basma.
245. Basma: I can see that.	
246. Sara: Can you see the stain?	Basma looks into eyepiece.
247. Basma: Yes. It's just going all around.	
248. Susan: Did you see the canals?	
249. Basma: Yea.	Sara begins to add some details to Richard's original
250.(Inaudible conversations)	diagram on the chalkboard.
251. Basma: Actually, none of our corn flakes were stained.	
252. Susan: Don't you agree, Eddie?	
253. Eddie: Say again.	
254. Susan: I mean if you can only find it happening on one slide then /// not on all three.	
255. Eddie: Yea, then that might be a little bit stronger evidence that you're looking at representative of what always happens.	
256. Susan: Hey, I've learned something in this class.	Susan laughs.

Knowing and Teaching Science:

Just Do It!

Botany 531 (23541) – 4 credits, Spring 2001
INSTRUCTORS: Drs. ___
TEACHING ASSISTANTS: ___

Course Intent: In order to effectively teach science, one must be able to DO science! This course is about doing science. It provides the opportunity to freely conduct hands-on investigative-based research with a living organism. Students will have ample opportunities to design and carry out experiments and will gain experience in the oral and written presentation of scientific data. Although this is not a course in "teaching methods", it will provide an opportunity to translate your experiences into the development of laboratory applications suitable for use in a 7-12 or undergraduate classroom.

Expected Outcomes: Students will gain increased confidence in working cooperatively and with minimal supervision, enhanced critical thinking skills, familiarity with the 'real' processes of science, increased familiarity with the formal aspects of scientific research (data collection, analysis and presentation). Students will sharpen their ability to design scientifically sound experiments using a variety of organisms and approaches.

Required Materials: 1) A Laboratory-Inscription Notebook. This will be used to record, on a daily basis, all activities, experiments, calculations, data, etc. associated with individual and group research projects. Number pages (if needed) and date all entries. Copies of completed sections are to be handed into ___ as called for (for periodic feedback) and the complete Notebook is to be handed in to him on April 16th. **2)** A VHS videotape and 3.5" formatted disc for documentation and transcript analysis of the pre- and post-course interviews. **3)** A copy of the self-scorable Myers-Briggs Type Indicator, available at the Service Desk in the Bookstore (under ___ Science Ed 496).

Location: Rm. 219 Hesler Biology Bldg. **Class Times:** MW 12:40 – 3:20

Organization: Most class periods will involve collaborative and/or independent design, implementation and observation of experiments. Because experiments with living organisms typically do not limit themselves to a MW schedule (!!) it is expected that, as necessary, students will work in the lab outside of regular class hours. All participants will have open access to the lab room.

Presentations:

1. Journal Club Presentation – individual. Choose an interesting paper from current scientific periodicals (biology) and present a critical overview and analysis to the class, ca. 15 min. (oral with visuals and/or handouts). The chosen paper should contain original research, not a review or summary of previous work.
2. Research Presentation on 'unknown' – individual or group of 2-3. Present a component(s) of the experimental work that you or your group have completed in your investigations of the 'unknown', ca. 15-30 min. (oral with visuals and a 'draft' of a formal written research report in the format of a scientific paper; final version due two weeks later).
3. Presentation of an Inquiry-based Lesson suitable for grades 7-12 – individual. This should be based on additional work with another organism that you have learned to work with and experimented with. The lesson should be derived from an experiment that you have designed and carried out with the organism. Additional information and guidelines will be provided as the course progresses. (ca. 15 min. oral and a formal written version).

Figure 3: Course Syllabus (continued on next page)

Grading:

1. (15%) Participation and Reflective Journal – active participation in individual and cooperative activities and discussions throughout the semester and upkeep and completion (hard copy and disc) of your personal Reflective Journal. (individual)
2. (10%) Laboratory - Inscription Notebook (individual)
3. (20%) Journal Club Presentation (individual)
4. (25%) Research presentation, oral and written. (individual or group)
5. (25%) Inquiry exercise and lesson. (individual)
6. (5%) Transcript and analysis of video from pre- and post- class interviews. (individual)

WEEK	**MONTH**	**MONDAY**	**WEDNESDAY**
One	**January**		10; Introduction, video interviews
Two		15	17
Three		22; e-mail MBTI results to ___	24
Four		29	31
Five	**February**	5; **Journal Club Oral Presentations**	7
Six		12; video transcripts due	14
Seven		19	21
Eight		26	28
Nine	**March**	5; Begin consideration of 2nd Organism options for inquiry lesson	7; **Oral Research presentations** 1st written draft due
Ten		12; Oral presentations continued	14; Dr. ___ will discuss development Of inquiry lessons. Begin work with Other organism
Eleven		19; SPRING BREAK	21; SPRING BREAK
Twelve		26	28; Deadline for written research paper
Thirteen	**April**	2	4
Fourteen		9	11
Fifteen		16; Inscription Notebooks due	18
Sixteen		23; **Presentations of Inquiry-based Exercises** (written & oral)	25; **Presentations continued**
Seventeen		30; Post-class video interviews And lab clean up	May 4; (FRI) video and video transcript with analysis and journal file due. If Dr. ___ does not receive these on this date An Incomplete will be issued for your grade

Figure 3 (continued)

An excerpt from: <u>Shaping the Future</u>, p. 4, National Science Foundation 1996 –
Comments from a research chemist at a major university about undergraduate education in her field –

"The classroom – it is embarrassing. Chalk and blackboard. There are hands-on experiments the students can do. However, these are largely cookbook... The textbooks....are large collections of facts. What I see really missing from these textbooks is the process of science. And finally, the exams....are a really nice way to give the student a grade, but I doubt that they really measure what the students are learning, where their critical thinking skills are."

Notes about Reflective Journals: Part of the grade for the course will be determined by your weekly reflections for Dr. ___. Use the following criteria to write about:
How do you feel about the course, so far?
What frustrations, if any, are you experiencing?
How are groups forming, if any?
How much do you understand about what you are supposed to be doing?
Is this course similar/dissimilar to previous science courses/experiences?
What is the nature of scientific thinking, and specifically, yours?
How is your own scientific thinking developing?
What is scientific thinking?
What is the nature of science?
Use any of the above topics in any order, in any frequency you wish.
(Note: Dr. ___ will not have access to the Journals until after the class has been completed.)
Method of communication with Dr. ___ - Please **DATE ALL ENTRIES!**

1. Type your journal weekly or biweekly in a word processing program. Send it via email to ___ . In addition, print out a hard copy and give it to___ who will deliver it to Dr. ___.

2. At the end of the semester, submit a computer disk with your entire journal file on it along with a hard copy of the file to Dr. ___. Label the disk with the kind of word processing program on it and whether MAC or IBM. This is due the day of the scheduled final exam period, May 4.

If you need course adaptations or accommodations because of a documented disability or if you have emergency information to share, please contact the Office of Disability Services at 191 ___. This will ensure that you are properly registered for services.

Figure 3 (continued)

Vita

Boyd Edward (Eddie) Lunsford was born in Cherokee County, North Carolina. He attended the public schools of the county and graduated from Andrews High School. He began his college studies while still in high school. He attended Western Carolina University in Cullowhee, North Carolina and ultimately earned three degrees while studying there. A Bachelor of Science in Education degree was completed in 1987. A Master of Arts in Education degree was completed in 1993 and an Education Specialist degree was completed in 1995.

While in graduate school, Eddie began teaching in local community colleges. In 1999, he entered the University of Tennessee, Knoxville as a graduate student in science education.