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ABSTRACT

The primary objective of this case study was to examine prospective secondary science teachers’ developing understanding of scientific inquiry and Mendelian genetics. A computer simulation of basic Mendelian inheritance processes (Catlab) was used in combination with small-group discussions and other instructional scaffolds to enhance prospective science teachers’ understandings.

The theoretical background for this research is derived from a social constructivist perspective. Structuring scientific inquiry as investigation to develop explanations presents meaningful context for the enhancement of inquiry abilities and understanding of the science content. The context of the study was a teaching and learning course focused on inquiry and technology. Twelve prospective science teachers participated in this study.

Multiple data sources included pre- and post-module questionnaires of participants’ view of scientific inquiry, pre-posttests of understandings of Mendelian concepts, inquiry project reports, class presentations, process videotapes of participants interacting with the simulation, and semi-structured interviews. Seven selected prospective science teachers participated in in-depth interviews.

Findings suggest that while studying important concepts in science, carefully designed inquiry experiences can help prospective science teachers to develop an understanding about the types of questions scientists in that field ask, the methodological and epistemological issues that constrain their pursuit of answers to those questions, and the ways in which they construct and share their explanations. Key findings included prospective teachers’ initial limited abilities to create evidence-based arguments, their
hesitancy to include inquiry in their future teaching, and the impact of collaboration on thinking. Prior to this experience the prospective teachers held uninformed views of scientific inquiry. After the module, participants demonstrated extended expertise in their understandings of following aspects of scientific inquiry: a) the iterative nature of scientific inquiry; b) the tentativeness of specific knowledge claims; c) the degree to which scientists rely on empirical data, as well as broader conceptual and metaphysical commitments, to assess models and to direct future inquiries; d) the need for conceptual consistency; e) multiple methods of investigations and multiple interpretations of data; and f) social and cultural aspects of scientific inquiry. This research provided evidence that hypothesis testing can support the integrated acquisition of conceptual and procedural knowledge in science. Participants’ conceptual elaborations of Mendelian inheritance were enhanced. There were qualitative changes in the nature of the participants’ explanations. Moreover, the average percentage of correct responses improved from 39% on the pretest to 67% on the posttest. Findings also suggest those prospective science teachers’ experiences as learners of science in their methods course served as a powerful tool for thinking about the role of inquiry in teaching and learning science. They had mixed views about enacting inquiry in their teaching in the future. All of them stated some kind of general willingness to do so; yet, they also mentioned some reservations and practical considerations about inquiry-based teaching.
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Chapter 1

SIGNIFICANCE OF INQUIRY IN SCIENCE EDUCATION

1.1 Introduction

The inclusion of science inquiry in the K–12 school curriculum has been one of the goals of science education for a long time. In the early 1900s, Armstrong, Dewey, and others advocated the teaching of science inquiry. In the late 1980s and 1990s science inquiry was emphasized again as a key component in curriculum reform efforts, such as the National Science Education Standards [NSES] (National Research Council, 1996) and Science for All Americans (American Association for the Advancement of Science, 1990). Both reform documents suggest that inquiry experiences in school science are central in understanding scientific inquiry and in promoting more meaningful science content learning.

When engaging in inquiry, students describe objects and events, ask questions, construct explanations, test those explanations against current scientific knowledge, and communicate their ideas to others. They identify their assumptions, use critical and logical thinking, and consider alternative explanations. In this way, students actively develop their understanding of science by combining scientific knowledge with reasoning and thinking skills (NSES, 1996, p. 2).

Essentially, reform documents strongly emphasize two key premises as crucial goals in science education. The first premise is to understand and experience science as a form of inquiry. According to this premise students should have the abilities to do and understand the nature of scientific inquiry (NRC, 1996, p. 23). The second premise suggests that students need learning experiences that include the unifying concepts and
processes in the sciences, such as system and organization, evidence and explanation, change and constancy, evolution and equilibrium, and form and function (p. 104).

The AAAS and NRC reform documents promote minimizing the number of facts taught in the curriculum in favor of treating fewer concepts with greater depth. While there is growing recognition of the importance of focusing on scientific inquiry, there is a great deal of ambiguity and variability in what is meant by scientific inquiry and what role it should play in instruction. According to the NSES, scientific inquiry refers to:

The diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work. Inquiry also refers to the activities of students in which they develop knowledge and understanding of scientific ideas, as well as an understanding of how scientists study the natural world. (p. 23)

Such standards are consistent with theories of cognition that argue that learning occurs best in actual contexts of use for the knowledge being learned (Brown & Campione, 1996; Lave & Wenger, 1991). In inquiry based teaching, students participate in investigations that require them to develop questions and hypotheses, collect data, analyze data, and draw and test conclusions. Inquiry learning typically seeks to excite curiosity in students, encouraging them to investigate questions on their own initiative and grounding this activity in a context. In addition to the basic abilities of conducting a scientific investigation, inquiry learning should include an understanding of how scientists do their work (NRC, 2000).

While strongly encouraging inquiry based pedagogy, the National Science Education Standards has placed changing emphases on teaching and learning practices. Khan (2002) summarized them as shown in Table 1-1.
Implementing inquiry-based teaching in order to create a learning environment for students to become scientifically literate is a challenging task for science teachers. The National Science Education Standards (1996) proposes six teaching standards for science teachers (Table 1-2) and defines eight categories of science content standards, including (1) Unifying concepts and processes in science, and (2) Science as Inquiry (p. 104).

Unifying concepts and processes include evidence, models, and explanation. Science as inquiry standards suggest that students develop: (a) An understanding of scientific concepts, (b) An appreciation of “how we know” what we know in science, (c) An understanding of the nature of science, (d) Skills necessary to become independent inquirers about the natural world, and (e) The dispositions to use the skills, abilities, and attitudes associated with science (p. 105).
As a result of engaging in the aforementioned activities, students are expected to not only develop an understanding of scientific concepts, but also to acquire the scientific inquiry process skills necessary to engage in scientific exploration. However, producing these desired outcomes in typical science classrooms is difficult. A teacher who wants to use inquiry learning faces a number of questions about identifying instructional materials that support inquiry and certain proven strategies make inquiry learning manageable and fruitful.

Computer simulations offer a new opportunity for teachers and students to collaboratively experience inquiry-based problem solving, construct knowledge, and engage in modeling as a part of science learning (Penner, 2001).

Teaching science as inquiry is a very complex activity by nature, and teachers have difficulties implementing inquiry into their teaching repertoire for various reasons. Researchers have indicated that translating inquiry-based teaching into classroom practice is a very challenging task for science teachers (Crawford, 2000; Keys & Kennedy, 1999; Tobin, Kahle, & Fraser, 1990). In order to yield desired outcomes in

<table>
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<th>Table 1-2: Teaching Standards of the National Science Education Standards</th>
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<tr>
<td><strong>Teaching Standard A</strong>: Teachers of science plan an inquiry-based science program for their students.</td>
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<td><strong>Teaching Standard B</strong>: Teachers of science guide and facilitate learning science.</td>
</tr>
<tr>
<td><strong>Teaching Standard C</strong>: Teachers of science engage in ongoing assessment of their teaching and of student learning.</td>
</tr>
<tr>
<td><strong>Teaching Standard D</strong>: Teachers of science design and manage learning environments that provide students with the time, space, and resources needed for learning science.</td>
</tr>
<tr>
<td><strong>Teaching Standard E</strong>: Teachers of science develop communities of science learners that reflect the intellectual rigor of scientific inquiry and the attitudes and social values conducive to science learning.</td>
</tr>
<tr>
<td><strong>Teaching Standard F</strong>: Teachers of science actively participate in the ongoing planning and development of the school science program.</td>
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students’ abilities and understandings, inquiry-based teaching should require the “conceptual identification of assumptions, use of critical and logical thinking, and consideration of alternative explanations” (NRC, 1996, p. 23). Some studies reported that science inquiry teaching is resistant to analysis and that the development and application of science inquiry remains problematic (Germann, Aram, & Burke, 1996).

Crawford (2000) presents five assertions about teaching inquiry in the science classroom: (a) Inquiry is situated in a context; (b) Teachers need to embrace inquiry as a content and a form of pedagogy; (c) Collaboration between teacher and students enhances inquiry; (d) Teacher and students’ roles are complex and changing; and (e) Greater levels of involvement are required by teachers than in traditional setting. All of these recommendations have implications for the role of the teacher in inquiry based science classroom.

1.2 The Problem and Need for Study

The National Science Education Standards articulate a vision of a teacher who acts as a critical decision maker, and who intervenes in the learning process at appropriate times in an effort to encourage, challenge, and focus students. Teachers also must decide when to challenge students to make sense of their experiences (NRC, 1996, p. 36). Research indicates a “pattern for general support for inquiry-based teaching” (Bransford, Brown, & Cocking, 2000; Haury, 1993; NRC, 2000, p. 126). Von Secker & Lissitz (1999) noted that little research is available describing how prevalent are NSES teaching strategies in science classrooms. They reported that teacher-centered instruction and text-based learning were still “typical” throughout the 1990s (p. 1111). In spite of all
the efforts to promote inquiry teaching and learning in schools, the practice of inquiry has rarely been successfully implemented by practicing teachers (Yager, 1997). Science teachers’ perceptions of inquiry and their abilities to implement inquiry-based teaching may be reasons for this failure. After more than two years of classroom observations, Gallagher (1991) concluded in one study that the 25 science teachers he followed focused on the body of knowledge of science. Further interviews with the teachers revealed that they had limited understanding of how scientific knowledge is formulated and validated. Some researchers have argued that it is imperative for researchers to examine how preservice teachers develop a knowledge base and practice of inquiry (Finley, Lawrenz, & Heller, 1992).

Considerable evidence shows that a teacher’s conception of the nature of scientific inquiry influences how they teach as well as what they teach (Brickhouse, 1990). Designing methods courses centered around an explicit emphasis on scientific inquiry and the nature of science helps prospective teachers develop adequate understandings of the nature of scientific inquiry (Bell, Lederman, & Abd-El-Khalick, 1998). Most prospective teachers have never experienced learning science as inquiry and never monitored an inquiry-based science classrooms (Boardman & Zembal-Saul, 2000).

Hypothesis testing has recently been presented very positively within the science education community, being promoted as a powerful context for supporting knowledge acquisition in science (Howe et al., 2000). The drive has come from reform documents, which emphasize the integrated acquisition of conceptual and procedural knowledge. Because hypothesis testing provides context where students can formulate conceptual knowledge into researchable ideas, investigate ideas through manipulation, prediction,
and observation, and evaluate ideas in the light of evidence, in principle, should allow integrated acquisition of knowledge. Despite longstanding scrutiny by researchers, hypothesis testing has not been adequately studied as a context for learning. The focus of prior research has not been the form of integration that hypothesis testing requires, where procedural knowledge is promoted as a means to conceptual growth.

A distinction exists between knowledge base of concepts, the theoretical core of science, and scientific inquiry skills. Lawson (1994; 2002) argued that inquiry skills have a separate knowledge base related to evidence, and these should be taught. Moreover, cognitive psychologists have also distinguished between learning science, learning about science, and doing science (Hodson, 1993; Kuhn, Amsel, & O'Loughlin, 1988). From a constructivist view of learning, inquiry based project work provides good possibilities for individual interpretation in the process of knowledge construction. In collaborating groups of students, negotiation of meaning and arriving at consensus are important tools to cope with discrepancies and disagreement.

1.2.1 Purpose and Research Questions

In this study, I explored prospective secondary science teachers’ developing understandings of scientific inquiry and basic Mendelian genetics within the context of a science education course. In addition, prospective teachers were provided opportunities to learn about technology tools, which they might later used in their own classrooms. Consistent with the views expressed in the Standards, I designed an instructional module to engage prospective secondary science teachers in investigation of inheritance patterns in domestic cats, using a computer simulation. The module requires students to integrate
two sets of knowledge: knowledge about the nature of scientific inquiry and knowledge about basic Mendelian genetics. In this context, learning about inquiry refers to the experiences of prospective secondary science teachers as they engaged in a scientific inquiry using genetic computer simulation, Catlab, as part of their coursework.

The research questions for this study are:

1. What is the nature of prospective secondary science teachers’ understandings of scientific inquiry and in what ways do these understandings change after engagement in guided inquiry that includes constructing and testing hypotheses?

2. What are prospective secondary science teachers’ understandings of Mendelian genetics and to what extent, if any, did participants develop understanding of Mendelian genetics concepts?

3. (a) From the prospective science teachers’ perspective, what were the instructional strategies and classroom interactions in this module that contributed to understanding of scientific inquiry and Mendelian genetics, as well as the development of abilities to do scientific inquiry?

(b) What were the prospective teachers’ intentions for using inquiry in their own classrooms in the future?

1.2.2 Significance of the Study

The current study focused on prospective secondary science teachers’ understandings of basic Mendelian genetics, and the extent to which they acquired abilities of how to do science as well as their understandings about science. This study will contribute to the research about developing and assessing scientific inquiry skills and
enhancing content knowledge for science teacher education programs. Research findings suggest that science teachers’ knowledge and beliefs are influenced by the types of experiences that they had during their preparation to teach (Crawford, 2000). Participating in this study was an opportunity for prospective science teacher to experience inquiry-based learning and to reflect on how they can implement inquiry into their own teaching in the future.

By examining learning processes of prospective secondary science teachers as they interact with computer simulation, and the guidance strategies that facilitate their learning in this study, we may be able to gain some insights into how to feasibly integrate computer simulations into our teacher preparation programs in order to enhance inquiry process skills. Data and insights attained from this investigation could be used to improve science teacher education programs in developing and tracking scientific inquiry skills and subject matter knowledge. In addition, this study will increase science educators’ awareness of the potential use of Catlab in enhancing the teaching-learning experience in the classroom.

Perspectives from social constructivist and socio-cultural views of learning shaped this study (Vygotsky, 1978; Wenger, 1998). According to this line of thinking, science learning can be viewed as a participatory process that includes the negotiation of the cultural practices of scientific communities. These cultural practices include constructing explanations, defending and challenging claims, interpreting evidence, using and developing models, transforming observations into findings, and arguing theories. In this framework, learning is regarded as a participatory process in which the learner gradually becomes an active member in a cultural community by learning its discourse.
practices, norms, and ways of thinking. From this perspective, knowing refers to belonging, participating and communicating (Wenger, 1998). The assumption is that in order to develop understanding of scientific inquiry as well as inquiry skills, students need to engage collaboratively in inquiry by asking and refining questions, designing and conducting investigations, gathering and analyzing data, making interpretations, drawing conclusions, and reporting findings in a social context.

One area of biology in which learners have difficulties is genetics (Johnson & Stewart, 2002). Essentially the area of genetics investigates biological patterns of inheritance and variation. Diversity of topics includes classical genetics of Mendel, cytological studies, and current research on the human genome. Most school textbooks introduce Mendelian genetics and the discussion of mathematical models of transmission patterns. A survey of high school teachers (Stewart, 1982) indicated that Mendelian genetics, meiosis and mitosis, and the chromosome theory of inheritance were considered among the most difficult as well as the most important topics of study for high school students. For these reasons it is important to understand how teacher educators can facilitate teachers’ understanding of scientific inquiry. This research focuses on prospective secondary science teachers’ understandings of basic Mendelian genetics and scientific inquiry and on the extent to which they acquire scientific process skills as a result of engaging in inquiry using computer simulation.

1.3 Importance of Using Technology Tools in Science Teaching

If a primary goal of science education is to develop scientifically literate critical thinkers, then a greater emphasis must be placed on developing students’ scientific
process skills and reasoning abilities. There must be a commitment by teachers to make inquiry an integral part of the science curriculum. To facilitate the development of scientific inquiry and reasoning skills, instructional technology should target student-centered activities that promote meaningful learning and critical thinking.

The use of learning technologies to support students in gaining a deeper understanding of a specific subject-matter is a viable use of technology. Learning technologies can also be used to enhance some of the cognitive processes that have been associated with inquiry in science, including generating ideas, coordinating ideas with evidence, evaluating findings, weighing alternative explanations, constructing models that can be useful for making later predictions, and generating further ideas and questions.

The Benchmarks for Science Literacy (AAAS, 1993) specifically states that:

Computers have become invaluable in science because they speed up and extend students’ ability to collect, store, compile, and analyze data, prepare research reports, and share data and ideas with investigators all over the world.

Some studies concluded that computer-assisted instruction was effective in improving students’ science achievement and problem solving skills at both the high school and undergraduate levels (Ferguson & Chapman, 1993; Levine, 1994). One kind of learning technology, computer simulations, can be used to improve the teaching of scientific processes along with content. Simulations provide a unique opportunity for students to interact with the dynamics of a model system and help them to conceptualize it (Windschitl, 1996). Computer simulations enable repeated trials of an experiment with considerable ease in a limited time, provide immediate feedback, allow simultaneous
observation, and offer a flexible environment that enables students to proceed with their own plans (Fisher, 1997; Mintz, 1993; Mintzes, Wandersee, & Novak, 1998). Computer simulations encourage students to use “what if” questions and support their hypothetical thinking by enabling them to test hypotheses after identifying and controlling variables (Lin & Lehman, 1999).

1.3.1 Mendelian Genetics Computer Simulation (Catlab)

Catlab is a computer simulation that allows students to generate various characteristics in cats and explore those characteristics by crossing specific “cats” (Kinnear, 1998). Catlab is designed for use in high school and undergraduate biology classrooms and, with appropriate scaffolds; it can also be utilized in middle school curricula. Students can collect and interpret data and draw inferences and conclusions about the nature of specific inheritance patterns by using the program to “mate” specified cats. Catlab was used to involve prospective secondary science teachers actively in science inquiry and in the learning of science, namely Mendelian inheritance. The use of a simulation can motivate learners to engage in the formulation and development of scientific concepts, and to interact with models of reality. My selection of the simulation, Catlab, was based upon several criteria, including the open-ended nature of the program. This aspect contributes to an inquiry laboratory format. Catlab is based upon a valid scientific model of an accurately depicted genetic population. Furthermore, most students have had common experiences with cats.

Catlab enables students to select traits, hypothesize about gene interactions, and decide which cats to cross. Catlab allows students to investigate various traits, including
coat color (white/nonwhite), amount of white spotting (extensive/some/none), density of pigment in the fur (agouti/non-agouti), tabby striping (mackerel/blotched), and the presence of a tail (tail/Manx).

Students using Catlab are required to examine, organize, and analyze data for patterns. They may recognize, identify, and extract data patterns that signal the characteristics of particular inheritance principles. Solution of the Catlab project problems involves hypothesis-testing and experimental design in addition to the use of mathematical procedures. The participants must, through skilled experimentation, gather data that is meaningful enough to deduce the mode of inheritance. In order to understand and isolate key components, and to coordinate prior knowledge with present evidence, they have to recognize not only domain specific concepts, but also qualitative representations of the problem.

1.4 Overview of the Study

In my research, I engaged prospective science teachers as learners in an exemplary, technology rich inquiry-based model to help them develop knowledge and skills addressed in teaching standard A, teaching standard B, teaching standard D, and teaching standard E. The instructional design of my study focuses on establishing conditions for collaborative inquiry in order to facilitate prospective teachers in developing scientific inquiry skills and learning Mendelian genetics. The study then analyzes potential changes in prospective teachers’ understandings. The vehicle for creating these conditions is a computer simulation. The pedagogical principles that guided this study were student interest, problem posing and solving, interpretation,
prediction, investigation, and distributed expertise. In this learning context, my role as an instructor was a participant of collaborative inquiry who contributed to the discourse with his expertise. While studying important concepts in science, learners should also develop an understanding of the types of questions scientists in that field ask, the methodological and epistemological issues that constrain their pursuit of answers of those questions, and the ways in which they construct and share their explanations. Prospective teachers were engaged in an inquiry activity in which they were asked to explore inheritance patterns in cats that required testing hypotheses and making predictions. A collaborative inquiry approach and socio-constructivist perspectives were employed as a model of instruction. Multiple data sources included pre and post-instruction questionnaires of students’ view of scientific inquiry, pre-posttest of understandings of Mendelian genetics concepts, inquiry project reports, and class presentations, semi-structured interviews. All data were transferred into NVivo qualitative data analysis software, and analyzed using the constant comparative method. To summarize, the key elements of collaborative inquiry in this study were experimentation, social negotiation, and explanation-building. The instructional goal of the module was to enhance the participants’ understandings of scientific inquiry and conceptions of Mendelian genetics.

In chapter 2, I provide a review of the research literature relevant to this study. In chapter 3, I discuss the context of this study and explain the instructional design of the module. Chapter 4 details the research method. I talk about theoretical framework, participants, data collection, and analysis. In chapter 5, I present findings and provide extensive discussion of the data. In chapter 6, I refine my assertions and conclusions of this study and provide recommendations for further research.
Chapter 2

LITERATURE REVIEW

2.1 Current Perspectives of Inquiry in Science Education

Other than helping learners to gain knowledge of the concepts of science and develop scientific thinking skills and problem solving abilities, one of the most ambitious goals of science education is helping them to acquire a better understanding of the arguments and reasoning behind currently accepted scientific knowledge and scientific inquiry skills (AAAS, 1990; Lavoie, 1993; NRC, 1996). As a component of “scientific literacy” this is related to students’ understanding of scientific inquiry and the nature of science.

To achieve a vision of a scientifically literate population the National Research Council stated that, “Inquiry is central to science learning” (NRC, 1996, p.2). In an effort to call attention to the importance of inquiry-based teaching in science classrooms and to increase understanding of inquiry, the National Research Council published Inquiry and the National Science Education Standards (NRC, 2000).

Inquiry, as a term, has been complicated by multiple interpretations and can mean different things to different people. The role of inquiry in science education has been described using many variants, including scientific processes, scientific method, experimental approach, posing and exploring questions, formulating hypotheses, designing investigations, gathering and analyzing data, achieving conceptual understanding, constructing scientific explanations, reasoning strategies, and reflecting by researchers in the field (Abd-El-Khalick et al., 2004). Researchers and educators have
attempted to describe what inquiry looks like in research laboratories (Dunbar, 1994), in computer enhanced environments (Roth, 2001; Soloway et al., 1997; Stratford, 1997), and in the classroom (Crawford, Krajcik, & Marx, 1999; Roth & Roychoudhury, 1993). In essence, in an inquiry based classroom, students participate in experiments and investigations that require them to develop questions and hypotheses, collect data, analyze data, and draw and test conclusions. Inquiry learning tries to provoke students’ interest, encouraging them to investigate questions on their own initiative and grounding this activity in authentic situations.

According to Haury (1993), inquiry-based science can produce scientific literacy, knowledge of science procedures, vocabulary, conceptual understanding, and positive attitudes toward science. Inquiry approaches foster the development of deep foundational knowledge in a content area (Bransford et al., 2000).

Substantial research supports the efficacy of inquiry as an instructional model. Inquiry and the National Science Education Standards (NRC, 2000) presents some of these research findings, drawing heavily upon a report called How People Learn (Bransford et al., 2000). This comprehensive report provides explanations as to why inquiry enjoys success as an instructional approach. A summary of its premises is presented in Table 2-1.
Work of cognitive psychologists has inspired ideas and arguments on how people learn science better (Driver, 1994; Metz, 2000; White & Frederiksen, 2000). Researchers developed several models of scientific thinking, logical thinking (Kuhn, D. et al., 1988; Lawson, 1991), and problem solving (Dunbar, 1994). Further research-based support for encouraging inquiry in science teaching is presented in the form of seven arguments, summarized by Lazarowitz and Tamir (1994, p. 98). Briefly, these arguments are:

1. Concrete activities and manipulatives help students grasp abstract concepts.

2. Inquiry participation allows students to experience the “spirit” of science and understand how it works.

3. Inquiry promotes the development of higher order thinking skills.

4. Inquiry promotes the development of basic skills, including communication and facility with science procedures.

Table 2-1: Summary of central premises from How People Learn

Understanding science involves more than obtaining a knowledge base alone, also included are comprehending what these ideas mean, application of these ideas, and strategies for scientific thinking and problem solving.

Students build scientific understanding (as well as misconceptions), at least in part, based upon observations they have made about the world around them.

Students modify scientific understanding when they discover conflicts between their observations of the natural world and their understanding, and then adapt new explanations that seem plausible to them.

Learning is a social activity, and students specifically “benefit from opportunities to articulate their ideas… challenge each others’ ideas, and in doing so reconstruct their own ideas” (p. 119).

Powerful learning situations involve metacognition, initiative, choice, and some degree of control on the part of the learner.

When students comprehend concepts, they are better able to transfer this understanding to new contexts.
5. Inquiry provides the opportunity to grasp the components of the scientific method, such as hypothesizing, assumptions, predictions, and conclusions.

6. Inquiry promotes habits of mind associated with science, such as openness, skepticism, curiosity, and honesty.

7. Students enjoy hands-on exposure to scientific ideas and may have increased motivation to learn science.

2.2 Cognitive Psychology and Learning in Science

Cognitive psychology has influenced research in science education by contributing several theories of how people learn and process information (Piaget, 1973; von Glasersfeld, 1992; Vygotsky, 1978). Three cognitive theorists who have been highly influential in understanding the process of human learning are Jean Piaget, David Ausubel, and Lev Vygotsky.

2.2.1 Learning Theories of Piaget, Ausubel, and Vygotsky

According to Piaget, knowledge is continuously constructed through the individual’s interactions with the environment. Piaget believed that an effective way of learning is to encourage the learner to reconsider his/her views of the world. An important step in this process is the experience of cognitive conflict (Gredler, 1992, p.225). Piaget claimed that children and adults use mental patterns (schemes) to guide cognition, and interpret new experiences or material in relation to existing schemes. However, for new material to be assimilated, it must first fit an existing scheme.

Similarly Ausubel argued that meaningful information is stored in networks of connected facts or concepts referred to as schemata. New information, which fits into an
existing schema, is more easily understood, learned, and retained than information that does not fit (Slavin, 1988). For both Piaget and Ausubel then, new concepts that are well anchored by, or attached to, existing schemes will be more readily learned and assimilated than new information relating to less established schemes.

The aspects of Vygotsky's work that have received most attention among science educators are his arguments for the cultural basis of cognition and for the existence of a "zone of proximal development" (Moll, 1990). In his words, ZPD is the distance between the actual developmental level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance or in collaboration with more capable peers (Vygotsky, 1978).

Despite these differences, these three learning theories depend on the existing cognitive frameworks that students bring to a learning environment. Prior cognitive structures are an important part of Piaget’s theory of cognitive development as its existing schemes. Ausubel made this abundantly clear, stating:

If I had to reduce all educational psychology to just one principle, I would say this: The most important single factor influencing learning is what the learner already knows. Ascertain this and teach him/her accordingly (Ausubel, Novak, & Hanesian, 1978, p.iv).

Vygotsky (1978), too, sought to show that scientific concepts develop fully as they incorporate related everyday concepts.

2.2.2 Constructivism

Constructivism is not a strategy but more like an underlying philosophy or way of seeing the world. Premises of this way of seeing the world are summarized in Table 2-2.
One reason for the broad, intuitive appeal that has fueled the growth of constructivism as an epistemological commitment and instructional model may be that it includes aspects of Piagetian, Ausubelian, and Vygotskian learning theories.

Von Glasersfeld’s work (1992; 1993) set forth several principles for describing knowing and knowledge in their development, nature, function, and purpose. First, knowledge is actively built up from within by individuals and by communities; knowledge is not passively received through the senses or by any form of communication. Second, social interactions between and among learners are central to the constructing of knowledge by individuals. Third, the character of cognition is functional and adaptive; cognition and the knowledge it produces are a higher form of adaptation in the biological context. Fourth, rather than the discovery of objective ontological reality, the purpose of cognition are to serve the individual’s organization of his/her experiential world.

Constructivism provides a sound theoretical foundation for explicating science pedagogy. Summarizing and interpreting the research literature on alternative

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<tr>
<th>The nature of reality</th>
<th>Mental representations have &quot;real&quot; ontological status just as the &quot;world out there&quot; does.</th>
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<tr>
<td>The nature of knowledge</td>
<td>Individually constructed inside people's minds, not &quot;out there.&quot;</td>
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<tr>
<td>The nature of human interaction</td>
<td>We rely on shared or &quot;negotiated&quot; meanings; better thought is more cooperative than authoritative or manipulative in nature.</td>
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<tr>
<td>The nature of science</td>
<td>It is a meaning-making activity with the biases and filters accompanying any human endeavor.</td>
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conceptions in science, Wandersee, Mintzes, and Novak (1994) pointed out that the cornerstone of this body of research rests on the evidence documenting claim that students harbor a wide variety of alternative conceptions about objects and events when they enter formal learning in science. Some characteristics of constructivist teaching models as summarized by Goldin (1990) are (1) knowledge is invented or constructed by human beings, (2) an interpretation of knowledge is constructed by the learner, (3) learning occurs most effectively through guided discovery, meaningful application, and problem solving, (4) and effective teaching involves the creation of classroom learning environments, and encouraging the development of diverse and creative problem solving processes in students.

Innovations in science pedagogy such as conceptual change teaching strategies hold much promise for dealing with students’ alternative conceptions. These strategies are grounded in constructivism, contemporary philosophy of science (Kuhn, 1970), and conceptual change theory (Posner et al., 1982).

2.2.3 Conditions for Conceptual Change

Posner, Strike, Hewson, & Gertzog (1982) indicated two different conceptual changes in students: assimilation and accommodation. Assimilation is the integration of new knowledge with existing cognitive structures. Accommodation is the adjustment of cognitive structures to a new situation. They noted several crucial conditions that must be fulfilled before accommodation can occur and described the educational conditions that promote conceptual change follows: (1) there must be dissatisfaction with existing conceptions. Scientists and students are unlikely to make major changes in their concepts
until they believe that less radical changes will not work; (2) a new conception must be intelligible; (3) and a new conception must appear initially plausible. Any new concept adopted must at least appear to have the capacity to solve the problems generated by its predecessors. Plausibility is also a result of consistency of the concepts with other knowledge; and (4) a new conception should suggest the possibility of a fruitful research program, potential to be extended, to open up new areas of inquiry (Posner et al., 1982, p. 214). In a general sense, conceptual change strategies focus on exposing the learner’s knowledge structure, then modifying it (Windschitl & Andre, 1998), as well as emphasizing the need for self-monitoring and controlling the events of learning.

2.2.4 Community of Learners

Research in cognitive and social psychology initiated new visions for the design of learning environments. In order to implement necessary elements into teaching and learning, new perspectives advocated the integration of curriculum, instruction, and assessment into one framework (Bransford et al., 2000). The construct of community of learners contributed to my curricular framework, and is consistent with current science education standards (NRC, 1996). Theories of cognition argue that developing understanding occurs in actual contexts of use (Brown & Campione, 1996; Lave & Wenger, 1991). Community of learners has its historical roots in the changes that have occurred in psychological learning theory over the last thirty years. Drawing from the related literature, Crawford et al. (1999) identified and reported six components of community of learners: 1) authentic task; 2) small group work; 3) negotiation of understanding; 4) public sharing of ideas; 5) collaboration with experts; and 6) shared
responsibility. Individual responsibility is coupled with communal sharing. Students and teachers each have ownership of certain forms of expertise. Students are divided into groups; each group reports their progress to date, and they give comprehensive checks to each other. Negotiation of understanding is the mode of activities in the classroom, and it is achieved through constructive discussion, questioning, and criticism. Discourse involving increasingly scientific modes of thinking, such as conjecture, speculation, evidence, and proofs, become part of the common voice of the community (Brown & Campione, 1996). Classrooms are conceived as comprised of multiple zones of proximal development through which students can navigate via different routes and at different rates. The characteristics of successful classrooms, according to this perspective, are listed in Table 2-3.

Brown & Campione (1996) described and disseminated the principles of the theory of community of learners for teachers so that they are free to design or modify any surface activity in ways that are consistent with the principles. Development of these principles was influenced, not only by cognitive psychology, but also by relevant branches of linguistics, sociology, anthropology, studies of apprenticeship (Lave & Wenger, 1991), and studies of communities of professional scientists (Latour, 1987; Latour & Woolgar, 1986). In the community of learners, there is strong emphasis on putting students in charge of their own learning as a result of long standing research on metacognition.
Table 2-3: Characteristics of Classroom to Create a Community of Learners (Adapted from Brown & Campione, 1996)

- Students and teachers each have ownership of certain forms of expertise, but no one has it all. Expertise is deliberately distributed through reciprocal teaching and collaborative learning activities.

- Students work in groups. Each group reports their progress to date; they give comprehensive checks to each other. The classroom teacher would conduct a benchmark lesson, model thinking skills and self-reflection, or encourage the class to pool its expertise in conceptualization of the topic.

- Constructive discussion, questioning, and criticism are expected to be the mode of activities in the classroom. Discourse involving increasingly scientific modes of thinking, such as conjecture, speculation, evidence, and proofs, become part of the common voice of the community.

- Theoretically, classrooms are conceived as comprised of multiple zones of proximal developments through which students can navigate via different routes and at different rates.

Vygotsky’s sociocognitive theory proposes that cognitive structures are first formed socially and then reconstructed internally (Moll, 1990). Cooperative learning is a popular notion and refers to students either cooperating in a group task or helping one another to achieve individual cognitive objectives. Commenting on one another’s knowledge-building efforts could become a natural and important activity in a community of learners.

Sociologists who have studied the practice of science (Latour, 1987; Latour & Woolgar, 1986) asserted that there are three important aspects of scientific practice: First, science is a collaborative activity (particularly in the sense that, while scientists might work individually to solve particular problems, the process of knowledge development in science involves the negotiation of meaning). Second, scientists use knowledge (often in the form of explanatory models) in the construction of new knowledge. And, third, scientists’ understanding of problems and problem-solving strategies changes during
knowledge construction. Therefore, science is not a body of knowledge to be transmitted from one who knows to one who does not yet know, but instead, it is a practice in which new knowledge is created and negotiated, in social contexts, in response to problems that arise with existing models.

2.3 Computer Technologies for the Science Classrooms

Some of the cognitive processes associated with inquiry in science include generating ideas; coordinating ideas with evidence, evaluating findings, weighing alternative explanations, constructing models that can be useful for making later predictions, and generating further ideas and questions. Various technology tools, embedded within the curriculum, can support inquiry-based teaching and meaningful learning in science classrooms by engaging students in cognitive tasks that otherwise might be too complex or prohibitive (Salomon, Perkins, & Tamar, 1991). Krajcik et al (2000) refer to such technology tools as learning technologies because of their potential to engage students in different aspects of inquiry and to support them in meaningful learning.

According to Zeigler and Terry (1992), five distinguishing features of the computer make it an ideal tool for utilization in the development of problem solving skills: (1) its interactive nature; (2) its shift of locus of control to the learner; (3) its ability to simulate experiments and model real situations; (4) its immediate feedback to student responses, and (5) its ability to perform expediently, operations or calculations that are impossible or impractical on paper.
Facilitating students’ learning of the nature of scientific models, the process of constructing models and the utility of models in predicting and explaining real-world phenomena is one of the main goals of science education. Linn & Hsi (2000) published a thorough examination of their project of 15 years called “Computer as Learning Partner.” They emphasized the importance of making science accessible to all students and the role that computers can play as a learning partner. Linn & Hsi (2000) provide convincing evidence that science curricula need to change and that students who explore a few important concepts of science will develop robust understandings of these areas and of scientific inquiry process.

2.3.1 Computer Simulations in Science Education

Computer simulations are particularly adept at representing complex processes such as photosynthesis or mechanism of inheritance. Constructivist approaches to simulation may give learners the opportunity to freely create, test, and evaluate their own hypotheses in a richly contextualized environment (Windschitl & Andre, 1998). These approaches encompass the elements of conceptual change strategies as described by current theory.

Instructional simulations are those simulations that are designed to function within a learning environment (de Jong, 1991). Simulations enable repeated trials of an experiment with considerable ease in a limited time, provide immediate feedback, allow simultaneous observation, and offer a flexible environment that enables students to proceed with their own plans (Mintz, 1993).
2.3.1.1 Instructional Strategies Associated with Computer Simulations

Simulations may be engaging for science learners because they are able to manipulate variables and observe changes. Research studies showed that the use of computer simulations designed to facilitate inquiry in science had variable effects on the development of inquiry skills such as being able to generate hypotheses (de Jong & van Joolingen, 1998), interpret data and evaluate arguments (Zembal-Saul et al., 2002), and make predictions. Although simulations appear to help students construct understandings of science content, the modeling process and scientific inquiry, a great deal remains to be understood about the ways in which students construct understandings of natural phenomena when engaged in making models or running simulations (Stratford, 1997).

According to some experts, computer simulations do not simply invite learners to exhibit processes such as hypothesis generation, prediction, or data interpretation (Frederiksen, White, & Gutwill, 1999; Krajcik et al., 2000; Roth, 2001); rather, experts have turned their attention to the instructional supports or scaffolding associated with the use of instructional simulation tools to develop these skills.

Vygotsky’s social constructivist view emphasizes the development of shared knowledge through social interaction and cooperative learning (Mintzes et al., 1998). Research suggests various instructional support mechanisms such as instructional prompts, information sheets (Lin & Lehman, 1999), and assignments that guide inquiry (de Jong & van Joolingen, 1998) to improve the usefulness of computer simulation learning that relies on discovery rather than instruction. Research also cautions educators concerning the excessive demands that unassisted discovery may place on students, particularly students of low ability (Berger et al., 1994). Scardamalia et al. (1994) used
computers to support student’s intentional learning and reported that when having
knowledge is set as a goal by students, use of the computer medium can make significant
contributions in fostering intentional learning. Intentional learning refers to the extent to
which students actively and strategically pursue learning as a goal.

2.3.1.2 Modifying Ideas and Remedying Alternative Conceptions

Zietsman & Hewson (1986) used computer simulation to diagnose and remediate
alternative conceptions about velocity. By stimulating hypotheses testing on the part of
the learner, computer-based teaching offered the possibility of conceptual conflict. Their
results indicate that simulations can be credible representation of reality, and that
remediation produced significant conceptual change in students holding alternative
conceptions.

Gorsky & Finegold (1992) studied how simulations might lead to conceptual
change using series of simulations involving forces on an object in which students could
indicate directions of forces on the object and then watch the results. They observed that
when modifications of existing schemata were minor, students tended to resolve
anomalies through independent thought. When major modifications were required
students often referred back to the simulation for more information. The researchers
stated that simulations led to cognitive conflict and were effective in eliciting students’
ideas about forces on objects.

2.3.1.3 Teaching Mendelian Genetics with Genetics Construction Kit

The Genetics Construction Kit (GCK) simulates the Mendelian genetics model. It
enables learners to generate realistic problems to solve and provides realistic data for
them to analyze. Slack & Stewart (1990) used the Genetics Construction Kit (GCK) to explore students’ problem-solving strategies and to develop a model of students’ performance.

In Slack & Stewart’s (1990) study, 35 students solved genetics problems which required them to reason from effects (phenotype data) to causes (genotype data). Data consisted of think-aloud protocols and computer generated information on the problems presented and crosses performed. They reported that students followed these problem solving strategies: an unplanned approach (lack of hypothesis and testing strategy), a working backward approach (explaining rather than predicting), and an approach emphasizing quantitative counting and ratios. Students lacked problem-solving abilities and skills such as genotypic thinking and generational thinking, focusing instead on phenotypical interpretations of data. The researchers concluded that computer simulations that provide a realistic problem solving environment are still not sufficient to elicit good problem-solving skills, because simulation does not help students develop connections between conceptual knowledge and problem solving strategies. They suggested explicitly teaching hypothesis generation and testing strategies and presenting genetics concepts and principles, so that relationships between concepts are obvious.

Hafner & Stewart (1995) implemented a model-revising approach in problem solving in genetics framework to analyze students’ heuristics. The authors reported that students used three general heuristics during model construction: search the model, test the model, and evaluate the model. Students extracted information from the cross that conformed and did not conform to the predictions of their models. They revised their models and evaluated them with respect to both the model’s explanatory and predictive
sufficiency using the simulation. Hafner & Stewart (1995) stated that the majority of students in this learning environment produced successful solutions to genetics problems.

Finkel (1996), observing students solving problems also using GCK, found that students were able to engage in model-revising problem solving successfully and were able to produce revisions of increasing complexity that were generally compatible with accepted scientific theory. One advantage of simulations such as GCK is that they allow students to engage in knowledge production in the classroom, significantly increasing the amount of research students can do, as compared to actually crossing fruit flies in the laboratory and observing their offspring.

Hackling and Treagust (1984) explored high school students’ understanding after instruction. The study aimed at investigating the concepts and propositions, which were necessary for understanding the mechanisms of inheritance and determining which concepts and propositions were not understood or misunderstood. The partially standardized interview results revealed that the concepts and propositions about chromosomes, genes, meiosis, and fertilization were necessary for an understanding of the mechanism of inheritance.

2.3.1.4 Using Catlab to Study Expert/Novice Problem Solvers

Simmons & Lunetta (1993) explored general patterns of problem-solving behaviors in experts and novices interacting with Catlab. Catlab is a genetic simulation that requires students to generate questions and hypotheses, choose control variables, gather and interpret generated data, and draw conclusions. Researchers implemented a three-part instructional strategy with three expert and eight novice problem solvers using
Catlab to identify differences between expert and novice problem solvers in their interactions with the simulation. The subjects were first directed to explore various traits in cats. In phase 2, the researcher had a brief interview with each subject about his/her actions and rationale. Phase 3 required the subjects to investigate and determine the inheritance pattern of the orange and tabby striping trait. They reported three levels of problem-solving performance. The successful problem solvers used systematic procedures, developed valid reasons for their results, and generated correct answers. The transitional or less successful problem solvers used less systematic procedures and generated some invalid explanations. In addition, they did not rule out alternative explanation that could account for their conclusions. Unsuccessful problem solvers exhibited most random approaches to the problem and did not use valid scientific explanations. They typically used circular definitions to justify their actions (Simmons & Lunetta, 1993).

2.4 Inquiry in Prospective Science Teacher Education

As stated in the National Science Education Standards, inquiry should be the standard of professional science teacher education, “Inquiry into authentic questions generated from student experience is the central strategy for teaching science” (National Research Council, 1996, p.31). It is rare to find a science classroom in which inquiry practices has been implemented (von Secker & Lissitz, 1999; Yager, 1997). Not only there has been resistance by science teachers to inquiry-based teaching, but also teaching science as inquiry has not been a central element of science teacher education. These standards clearly suggest that inquiry forms of teaching should play an important role in
teacher educators’ work with prospective teachers. The teachers’ understandings of what science is and how students learn science in schools have formed a consistent system of beliefs for guiding classroom activities (Brickhouse, 1990, p.60). Therefore, teachers’ understandings of scientific inquiry are of particular importance because it can influence decisions about what is taught and how it is taught.

Defining precisely what inquiry teaching is and how it should proceed in the classroom is quite difficult (Bonnstetter, 1998), and adds to the problem of specifying the role a teacher in an inquiry form of teaching. Given the diverse and sometimes ambiguous articulations of the role of a teacher in inquiry science teaching, uncovering a particular role for the teacher that is essential or most effective is a difficult task. What seems to emerge from recent recommendations for science teaching is a rethinking of the teacher’s role from initiator and controller to guide and facilitator (Brown & Campione, 1996; Crawford, 2000). This means that the teacher is being asked to adopt a strong role as a guide who focuses and challenges students as well as provides opportunities for students to initiate and conduct their own investigations.

Rather than being an integral part, scientific inquiry usually, is addressed, in science education methods courses, as a topic of reading and discussion. Science teacher educators are recently trying to address these problems by designing courses for prospective teachers by including scientific inquiry into their curricula (van Zee, Lay, & Roberts, 2000; Windschitl, 2003). However, the current practice of science teaching indicates that research on the essentials of implementing inquiry into science classrooms is still needed (Songer, Lee, & Mcdonald, 2003). Limited numbers of studies report attempts to assist prospective elementary teachers in developing an understanding of
scientific inquiry. For example, after implementing inquiry-based science teaching in their program Zembal-Saul, Starr, & Krajcik (1999) suggested that students developed a better understanding of the importance of cognitive engagement through the use of prediction, discussion, inquiry activities, and questioning. Mulnix & Penhale (1997) successfully used the collaborative model to simulate the activities of scientists when conducting research projects and communicating findings with peers.

Zembal-Saul et al (2002) engaged prospective science teachers in an extended investigation using software designed specifically to support learners in making scientific explanations. They reported that when used appropriately, scaffolding strategies embedded in software can support learners in articulating and developing evidence-based scientific explanations.

Windschitl (2003) reported that only about 20% of the prospective teachers in the class had previously conducted only one open inquiry. In his methods class, scientific inquiry was introduced and discussed and participants were required to generate and investigate their own science research questions. At the conclusion of the course, participants were more enthusiastic about using inquiry; however, they did not consistently implement inquiry into their practices, only half of the participants used inquiry in their student teaching. Therefore, it seems that having experience with inquiry projects alone is not enough to ensure that prospective teachers will use inquiry teaching in their future classrooms.

Crawford (1999), describing a case study about a prospective teacher who was learning how to design and implement inquiry learning in her classroom, stated that it is realistic to expect that novice teachers can design and implement inquiry-based
instruction when they are provided with adequate support, and proposed five recommendations for supporting such teachers in achieving inquiry based instruction: (1) explore their beliefs about science and about teaching as a first step in initiating them to think about the characteristics of inquiry-based learning environments, and this was also echoed later by Hogan and Berkowitz (2000). Keys & Kennedy (1999) supported this argument by stating “Clearly, more research is needed on teachers’ views of inquiry and how they actually implement inquiry with their students”; (2) involve prospective teachers in opportunities to undertake authentic investigations; (3) provide models of teaching about scientific inquiry in field placements; (4) scaffold prospective teachers in planning long term units that relate to important questions and link to science content; (5) engage prospective teachers in collaborative inquiry of their own teaching.

In summary, based on from Crawford’s first and mainly second recommendations my research focuses on prospective secondary science teachers’ understandings about science and on the extent to which they acquired abilities of how to do science as well as their understandings of basic Mendelian genetics. Knowledge about science includes: a) different kinds of questions suggest different kinds of scientific investigations; b) current scientific knowledge and understanding guide scientific investigations; c) scientific explanations are based on data and emphasize evidence; d) scientific explanations must be not only logically consistent, but also open to questions and possible modification; e) science advances through legitimate skepticism; f) results of scientific inquiry whether new knowledge and/or methods emerge from different types of investigations and public communication among scientists (National Research Council, 2000). The abilities of how to do science includes: a) identifying questions and concepts that guide scientific
investigations; b) designing and conducting scientific investigations; c) gathering, analyzing, and interpreting data; d) formulating and revising scientific explanations using logic and evidence; e) recognizing and analyzing alternative explanations; and f) communicating and defending a scientific argument (National Research Council, 2000).
Chapter 3
COURSE DESIGN & CONTEXT OF THE STUDY

3.1 Introduction

The context for the study was a teaching and learning course focused on inquiry and technology for prospective secondary science teachers, SCIED 410, Technology Tools for Supporting Scientific Inquiry. SCIED 410 was part of a three-course sequence for prospective science teachers. The goal of the course was to help prospective science teachers develop an understanding of scientific inquiry while developing skills in using contemporary technologies by creating an environment for teaching and learning of the scientific inquiry as science content, in alignment with recommendations of the NSES. The Catlab module offered an opportunity to focus on scientific inquiry, by hypothesis testing and modeling activities, and technology use in classroom. The three credit course was required of secondary science education majors.

One of the challenges in helping prospective science teachers to learn about scientific inquiry is embedding their work in appropriate social context and creating a culture of collaboration and inquiry. This chapter describes my effort to combine research and incorporate a collaborative learning environment. My instructional design was aimed at providing enabling conditions for collaborative inquiry in developing scientific inquiry skills and learning Mendelian genetics implementing a computer simulation into the curriculum. Intertwining design and research is particularly important for establishing collaborative context and cultural structure that support collaboration. I argue that
structuring scientific inquiry as investigation to develop explanations presents meaningful context for the enhancement of inquiry abilities and understanding of the science content.

### 3.2 Theoretical Foundation for the Design of the Module

Design-based research (Brown, 1992) is an emerging paradigm for the study of learning in context through the design and study of instructional strategies and tools. I designed the module to engage prospective science teachers as learners in an exemplary inquiry based module for developing knowledge and skills addressed in teaching standards such as: 1) teachers of science plan an inquiry-based science program for their students; 2) teachers of science guide and facilitate learning science; 3) teachers of science design and manage learning environments that provide students with the time, space, and resources needed for learning science; and 4) teachers of science develop communities of science learners that reflect the intellectual rigor of scientific inquiry and the attitudes and social values conducive to science learning (NRC, 1996).

According to the philosopher Philip Kitcher (as cited in Cartier, 1999) inquiry in genetics includes: (a) specification of the number of relevant loci and the number of alleles at each locus; (b) specification of the relationship between genotypes and phenotypes; (c) specification of the relations between genes and chromosomes, of facts about the transmission of chromosomes to gametes and about the details of zygote formation; (d) assignment of genotypes to individuals in the pedigree.

Kitcher also describes how genetics might be used in inquiry: After showing that the genetic hypothesis is consistent with the data and constraints of the problem, the principles of cytology and the laws of probability are used to compute expected
distributions of phenotypes from crosses. The expected distributions are then compared with those assigned in part (d) of the genetic hypothesis.

Inquiry teaching and learning can occur at several levels, from, highly structured activities to open inquiry based on goals of instruction. The levels are: (a) confirmation activity, (b) structured inquiry, (c) guided inquiry, (d) open inquiry. In this study I designed a guided inquiry based module.

3.2.1 Social Constructivist Views of Learning

Consistent with current science education standards (NRC, 1996) and theories of cognition, the Catlab module was shaped by the social constructivist and socio-cultural views of learning (Brown & Campione, 1996; Vygotsky, 1978; Wenger, 1998).

According to this line of thinking, science learning is a participatory process that includes the negotiation of the cultural practices of scientific communities. These cultural practices include constructing explanations, defending and challenging claims, interpreting evidence, using and developing models, transforming observations into findings, and arguing theories. In this framework, learning is a participatory process in which the learner gradually becomes an active member in a cultural community by learning its discourse practices, norms, and ways of thinking. From this perspective, knowing refers to belonging, participating and communicating (Wenger, 1998). In order to develop understanding of scientific inquiry as well as inquiry skills, learners need to engage collaboratively in inquiry by asking and refining questions, designing and conducting investigations, gathering and analyzing data, making interpretations, drawing conclusions, and reporting findings in a social context. As a result of engaging in these
activities, students not only develop an understanding of scientific inquiry and concepts, but also acquire the scientific inquiry process skills necessary to engage in scientific exploration. The construct of “community of learners” has its historical roots in the changes that have occurred in psychological learning theory over the last thirty years (Brown & Campione, 1996).

3.2.2 Learning Science, Learning about Science, and Doing Science

A distinction exists between a knowledge base of concepts, the theoretical core of science, and scientific inquiry skills. Lawson (2003) argued that inquiry skills have a separate knowledge base related to evidence that should be taught. Moreover, cognitive psychologists have also distinguished learning science, learning about science, and doing science (Hodson, 1993; Kuhn, D. et al., 1988). From a constructivist view of learning, inquiry-based project work provides good opportunities for individual interpretation in the process of construction of knowledge. In collaborating groups of students negotiation of meaning and arriving at consensus are important tools to cope with discrepancies and disagreement.

3.2.3 Mendelian Inheritance Computer Simulation

Catlab is a software program that allows students to generate various characteristics in cats and explore the inheritance of those characteristics. Catlab is based upon a valid scientific model of a genetic population. The simulation was used as a medium that has the potential to involve learners actively in science inquiry and in the learning of science.
We cannot teach process of science without content. Using Catlab teachers can ascertain students’ analytical pathways in testing hypotheses (see Figure 3-1). Teachers can, therefore, identify the loci of students’ impasse in inquiry processes and underlying genetics concepts. We need studies which investigate how instructions using simulations can be designed in order to effectively enhance students’ scientific inquiry processes and support students’ concept learning in science.

Catlab enables students to select traits, hypothesize about gene interactions, and test these hypotheses by crossing selected cats. The traits students can investigate with Catlab include coat color (white/nonwhite), density of pigment in the fur (agouti/non-agouti), amount of white spotting extensive/some/none), tabby striping (mackerel/blotched), and the presence of a tail (tail/Manx). Figure 3-2 shows the general outlook of the software.
The instructional module engaged prospective teachers in an inquiry activity in which they explored inheritance patterns in cats using Catlab. Class projects required testing hypotheses and making predictions. A collaborative inquiry approach and socio-constructivist perspectives were employed to create a teaching and learning environment. Collaborative inquiry involves cognitive interactions between both teacher and students, and students with each other (Crawford, 2000).
In order to investigate coat color and pattern in cats, participants first added cats to the litter specifying coat color and pattern related traits, simulation leads the user to specify (see Figures 3-3 3-4 3-5).
Figure 3-3: Selecting traits in Catlab I

Figure 3-4: Selecting traits in Catlab II
Catlab has built-in chi square test to allow users to run test of fitness for their hypotheses (see Figure 3-6). As many as 118 kittens can be added to the litter and they can be sorted according to sex, coat color, pattern, and/or other specific characteristics.
After traits of parent cats selected, offspring can be created by mating them. Catlab provides graphical representation of the kittens before adding them into the litter (see Figure 3-7). F2 generation can be created by mating two kittens from F1 generation or more kittens can be generated by repeated mating of some parents.

Figure 3-7: Adding kittens into the litter

3.3 Scientific Inquiry Module

The most common suggestion from previous learning theories and research studies is to give learners appropriate experiences about the topic in order to help them to construct knowledge. Observing a phenomenon, developing hypotheses, and testing the hypotheses are key tasks in the experience of the learners. Using computer simulation by itself does not necessarily induce cognitive dissonance. Constructivist teaching methods
and conceptual assignments were included in the instruction. These conceptual assignments involved natural phenomena from real life related to genetics.

Participating prospective science teachers were in numerous science disciplines. After an initial survey of Mendelian genetics knowledge, four participants who were in secondary science education with an emphasis in biology volunteered to conduct a review of Mendelian genetics concepts for their peers. The major topics they reviewed were: Mendel’s laws of heredity; Monohybrid - Dihybrid crosses, including concepts like dominant, recessive, allele, homozygous, heterozygous, multiple-alleles and incomplete dominance, sex-linked inheritance. After the volunteer prospective teachers presented their reviews, I demonstrated how to use the Catlab to test hypotheses and provided participants with example problems to work on together. Twelve participants were paired according to their undergraduate majors (see Table 3-1). For example, four of twelve participants were secondary education majors who were seeking certificate to teach biology, they formed two pairs. I decided to assign pairs according to their background in order to create more homogenous pairs so they can have more meaningful interaction.

Moreover I was able to compare across between pairs who had different science background.

<table>
<thead>
<tr>
<th>Names</th>
<th>Majors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lisa &amp; Wilson</td>
<td>Both in Sec. Ed. Biology (Sec. Ed: Secondary Education)</td>
</tr>
<tr>
<td>Karen &amp; Rachel</td>
<td>Both in Sec. Ed. Biology</td>
</tr>
<tr>
<td>Kevin &amp; Ben</td>
<td>Sec. Ed. Earth and Space Science &amp; Geosciences</td>
</tr>
<tr>
<td>John &amp; Mary</td>
<td>Sec. Ed. Earth and Space Science &amp; Secondary Education Physics</td>
</tr>
<tr>
<td>Ashley &amp; Mike</td>
<td>Both in Sec. Ed. Earth and Space Science</td>
</tr>
<tr>
<td>Kate &amp; Valerie</td>
<td>Sec. Ed. Chemistry &amp; Sec. Ed. Earth and Space Science</td>
</tr>
</tbody>
</table>
Whole class worked on and completed structured inquiry activity using Catlab in the second session. Both Mono and Dihybrid cross scenarios were covered by the examples, showing participants how to test a hypothesis in each situation. Participants tested another hypothesis on their own using Catlab, followed by a class discussion. Issues such as assumption, prediction, collecting data, evidence, experimental design, controlling variables, and testing hypothesis were focus of the discussion. Mono and Dihybrid crosses were revisited during this discussion, participants often referred to the punnet squares that would result from the selected crosses. Participants were given four driving questions (Appendix E) and asked to choose one for their inquiry projects with an option to develop their own questions. Figure 3-8 demonstrates learning sequence and related activities during the module.

Figure 3-8: Learning sequence in Catlab module

In the third session, the six pairs of participants started to work on their inquiry projects at separate work stations; all pairs selected their driving questions from the list they were given, two questions were investigated by two groups. Table 3-2 provides the
participants gathered data from the computer simulation and challenged to generate relationships between traits that accounted for patterns of inheritance in the data. Participants were encouraged to form hypotheses about these relationships and to test them.

Table 3-2: Class Sessions and Activity Descriptions

<table>
<thead>
<tr>
<th>Session number (Date)</th>
<th>Description of activities complementing the inquiry project</th>
</tr>
</thead>
</table>
| 1 (2/13/2003)         | • Introduction to Mendelian Genetics: Major concepts and operations were presented by the volunteer students who majored in Sec Ed. biology; followed by class discussions on exercise problems which were provided by the instructor.  
• Introduction to Catlab: Using the computer simulation was demonstrated by the instructor. |
| 2 (2/18/2003)         | • Sample Catlab investigations were carried out by the instructor to demonstrate how to collect data and work with the program during hypothesis testing  
• Student pairs engaged in Catlab, testing another hypothesis on their own  
• Class discussion on the activity and evaluation of the proposed solutions. |
| 3 (2/20/2003)         | • Student pairs work on their inquiry projects.  
• Discussion on probability, Mono and Dihybrid crosses. |
| 4 (2/25/2003)         | • Preliminary project presentations to peers.  
• Continuing on inquiry projects. |
| 5 (2/27/2003)         | • Continuing on inquiry projects.  
• Class discussion on observation vs. inference and assumption vs. evidence to scaffold participants’ understandings. |
| 6 (3/4/2003)          | • Continuing on inquiry projects.  
• Discussion about building and testing hypothesis and role of models in science. |
| 7 (3/6/2003)          | • Final inquiry project presentations. |

Classroom activities and interactions focused on generating ideas, gathering data, and critiquing results and conclusions (see Table 3-3). Numerous participants thought they had answered their driving question at the end of the third session, consulting with
others I decided to have preliminary results presentations in the beginning of fourth session.

Table 3-3: Classroom Activities

<table>
<thead>
<tr>
<th>Generating ideas</th>
<th>Questions for or as a results of inquiry</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Hypothesis or rules of relationships between variables</td>
</tr>
<tr>
<td></td>
<td>Explanations (causal relationships)</td>
</tr>
<tr>
<td>Gathering data</td>
<td>Data from crosses in Catlab</td>
</tr>
<tr>
<td></td>
<td>Generating and selecting relevant data</td>
</tr>
<tr>
<td>Evaluating results</td>
<td>Data analysis; Logical and conceptual consistency</td>
</tr>
<tr>
<td></td>
<td>Considering experimental evidence and constructing arguments using this evidence</td>
</tr>
<tr>
<td></td>
<td>Considering alternative explanations</td>
</tr>
<tr>
<td>Content</td>
<td>Domain specific content knowledge</td>
</tr>
<tr>
<td></td>
<td>Domain specific cognitive skills, such as punnet squares</td>
</tr>
</tbody>
</table>

Pairs presented their findings and initial arguments, multiple relationships were generated by the pairs and presented to the whole class. Although pairs were working on different questions they were all dealing with the same set of genes. There was a lot of overlap in the findings; however pairs’ reasoning and explanations varied. Vigorous peer discussions arose when participants saw the anomalous data of others, and when they had different explanations for the data presented. After preliminary presentations, participants went back to work stations and continued their inquiry project evaluating new information and insights from their peers. Some participants tried to disprove their peers’ claims to make their own claims more plausible.
Participants collaborated between and within groups, as well as with the instructor. Sometimes pairs used someone else’s expertise to come up with an explanation for their data. As participants progressed with their investigation they tried to build a valid model for coat color and pattern inheritance in cats. Participants were constantly revising their models as they continued testing new hypotheses.

During the seventh and final class session of the module, the prospective science teachers shared investigation results with peers via computer projection. In order to provide each pair with enough time to present findings and to have discussions and criticism, presentations were done in two separate rooms with three pairs in each room. Each group presented findings and proposed inheritance models, highlighting models’ features and discussing what their model predicted for the particular traits.

The presentations provided an opportunity to discuss inheritance patterns and compare results across groups. At the end of the presentations, the instructor took the lead to combine all findings and come up with a grand model of inheritance for domestic cats. In this learning context, the role of the instructor was a participant of collaborative inquiry who contributed to the discourse with his expertise. To summarize, the key elements of collaborative inquiry in this study were: experimentation, social negotiation, and explanation-building. The instructional goal of the module was to develop the students’ conceptions of Mendelian genetics; the activity itself involved collaborative inquiry and experimentation using computer simulation.
3.3.1 Computer Enhanced Learning Environment and Role of the Teacher

Catlab module design had two major characteristics worth noting: First, it was designed to sustain scientific inquiry process with the integration of Catlab simulation, secondly a general instructional framework, guided inquiry, and classroom interactions was driven by theories on how people learn. The inquiry-based module embedded structured as well as open-ended activities for pairs of prospective science teachers. Participants made inferences about the causal mechanisms of inheritance in cats’ coat colors. Activities listed in Table 3-4 tried to address multiple processes that are associated with the inquiry such as testing ideas, making comparisons, and collecting data to name a few. Table 3-5 summarizes the major concept, main teaching methods within computer affordances, software features, and the role of the teacher in this module.

<table>
<thead>
<tr>
<th>Concepts</th>
<th>Instructional Methods</th>
<th>Software Features</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mendelian genetics</td>
<td>Model revising problem solving in genetics. Simulated genetics experiments. Practice simple and co-dominance problems. Driving questions. Whole class discussion of hypothesis testing. Small groups</td>
<td>Simulated genetics lab. Select parent cats and mate them. Traits and variations of kittens are displayed. Quickly create a large number of offspring across generations and view results</td>
</tr>
</tbody>
</table>

In guided inquiry, the teacher provides research questions and students design their own investigations to collect data and coordinate the data collection with analysis. Since students have to create data that will answer the questions, guided inquiry provides valuable experience in which students come to understand how evidence and argument
are used to support knowledge claims (Windschitl, 2003). Figure 3-9 demonstrates teacher and students activities in a guided inquiry approach.

Figure 3-9: The guided inquiry approach
My role, as an instructor and researcher during the Catlab module, was very similar to the ten roles Crawford (2000) reported in her study. These roles include motivator, diagnostician, guide, innovator, experimenter, modeler, researcher, mentor, collaborator, and learner. Participants acknowledged all of these roles when they were asked in interviews. The teacher’s role will be further discussed in chapter 5 along with findings from interviews.

### 3.4 Summary

In this chapter I have provided a theoretical rationale for the design of the Catlab module and described the module and the Catlab simulation in detail. In the next chapter I will describe the methods of inquiry for the data collection, and analysis of this research.
Chapter 4

RESEARCH DESIGN & METHODOLOGY

4.1 Overview

In this research, a qualitative case study approach was employed to study prospective secondary science teachers’ understandings of scientific inquiry and basic Mendelian genetics concepts. The participants were twelve prospective secondary science teachers, majoring in biology, earth and space science, physics, and chemistry, who were enrolled in an innovative science method course.

Merriam (1998, page 6) noted that:

Qualitative researchers are interested in understanding the meaning people have constructed. The key concern is; “understanding the phenomenon of interest from the participants’ perspectives.

In case studies, researchers use variety of methods to collect data (interviews, observations, documents, audio-visual materials, archival records, etc.). However, researchers, conducting case studies, face a strategic choice in deciding how much and how long the complexities of the case should be studied (Stake, 1995). The data gathering methods in this study were: pre- and post understanding of scientific inquiry and Mendelian genetics tests, participants’ inquiry project reports and presentations, one-on-one semi-structured interviews with seven selected participants, researcher’s (acting as a teacher) observations and interaction with the participants.

In this chapter, I will describe the specifics of the research design as well as methods of investigation. Since I was the researcher and the teacher during the module in
which the study was conducted, I will discuss my roles as teacher/researcher. To enhance the quality of the research and ensure trustworthiness of the findings, specific checks were built into the study. Finally, I will describe these checks to ensure that the data had been gathered accurately, analyzed critically, and interpreted in context.

4.2 Theoretical Framework of Research Design

I used qualitative inquiry methods for research design in this study. Qualitative research includes several forms of inquiry that helps us to understand and explain the meaning of social phenomena with as little disruption of the natural setting as possible (Merriam, 1998). Specifically, I structured the research design within a theoretical framework of a grounded theory inquiry tradition that is applied within case study design (Creswell, 1998; Strauss & Corbin, 1998).

Regardless of the unit of analysis, a qualitative case study seeks to describe that unit in depth and in detail, in context and historically (Patton, 1990, p.54). Qualitative inquiry is explanatory and inductive. Rather than making prior assumptions, it allows for dimensions to emerge from patterns found in data. Therefore, the findings are grounded in specific context (Strauss & Corbin, 1998). The overall approach to the research design followed the case study tradition of qualitative inquiry. A single case study is an empirical inquiry that investigates a phenomenon within its real-life context, especially when the boundaries between phenomenon and context are not clearly evident (Yin, 1994).

The purpose of this case study research was to explore prospective secondary science teachers’ developing understandings of scientific inquiry and basic Mendelian
genetics concepts within a particular context. In order to achieve this purpose, I decided to apply grounded theory tradition for data analysis.

4.2.1 Case Study

The case study approach appeared appropriate for this research because it allows flexibility to explore the classroom context while simultaneously focusing on the individual learners as well. The case study produced a detailed description of participants’ understandings of scientific inquiry and basic Mendelian genetics concepts and major features of classroom dynamics that facilitated inquiry based teaching and learning in computer simulation integrated module. This classroom is referred to as the primary case. Case studies are very popular among science educators because they have been very useful in gaining valuable insights regarding many issues.

A case study design is employed to gain an in-depth understanding of the situation and meaning of those involved. The interest is “in process rather than outcomes, in context rather than a specific variable, in discovery rather than confirmation (Merriam, 1998, p. 19).

The design of the instructional module was inspired by theoretical frameworks from cognitive psychology and science education, as described in Chapter 2. Further, I predicted that the entire experience would have a positive influence on the prospective secondary science teachers’ scientific inquiry and Mendelian genetics understandings. The phenomenon of interest was inextricably tied to the context; it was virtually impossible to identify specific variables that influenced understandings and relationships between them. Case study research concentrates on many if not all of the variables present in the phenomenon.
A case study, according to Creswell (1998) is an exploration of a “bounded system” or a case over time through detailed, in-depth data collection from multiple sources and rich in context. This study centered on a case of prospective secondary science teachers engaged in learning about scientific inquiry and Mendelian inheritance via their participation in an innovative instructional module involving testing hypotheses and building an inheritance model using computer simulation.

4.2.2 Grounded Theory

In grounded theory methodology, data gathered during the study direct the design of each step of the study as it evolves. The categories, themes, and subsequent hypotheses that emerge are “grounded,” have their initial foundation, in the data themselves (Creswell, 1998). This process is used for hypotheses generation rather than hypotheses testing. The procedure is suitable for social units of any size, ranging from men and nations to small organizational units such as a science class in a school.

Glaser and Strauss (1967) detailed various operations for generating grounded theory including:

. . . The discovery of important categories and their properties, their conditions and consequences; the development of such categories at different levels of conceptualization; the formulation of hypotheses of varying scope and generality;

. . . Integration of the total theoretical framework . . . [the] search for comparisons involving the discovery of useful comparison groups is essential to the generation of theory (p. 169).

This is an inductive reasoning process employed to generate hypotheses and theory. Two appropriate procedures utilized to gather data are in-depth interviews and participant observations. Two major aspects in evolving grounded theory are the constant
comparative method and theoretical saturation. The constant comparative method involves the process of joint collection and analysis of data while constantly comparing segments of data within groups and between groups (Strauss & Corbin, 1998). The purpose of these comparisons is to gain insights that can be transformed into relevant categories, properties, and hypotheses.

The constant comparative method is a means of stimulating the emergence of insights grounded in the data which leads to: (a) simultaneous grouping of the issues surfaced by respondents into categories, (b) the identification of the properties in these categories, and (c) the provision of clues for possible relationship among categories. When categories are saturated and clues relating categories are noted, the researcher can integrate categories, propose hypothesis, and tie hypotheses into theory (Glaser & Strauss, 1967).

4.3 Data Collection

I described the context of this research study in detail in chapter 3. The description of recruiting participants, sampling criteria, and data collecting methods is presented in this section.

4.3.1 Research Participants

In spring 2003 semester, during a class session prior to the beginning of the study, prospective secondary science teachers who enrolled in the SCIED 410 course were invited to participate in the study. The purpose of the study was explained as well as the time commitment required for participation. Potentially, the only activity required of participants other than normal participation in the course activities was an interview after
the instructional module. I did not offer any incentives for participating. They were assured that their participation would be totally voluntary and there would be no punishment for not participating or withdrawing at any time. After the invitation, the volunteer prospective teachers were asked to complete a Human Subjects Consent Form (Appendix A). All of the 12 prospective secondary science teachers enrolled in the course agreed to participate.

A minimum of 6 participants (3 pairs) decided to be necessary to provide a rich data set with which to pursue the research questions. I interviewed one additional participant because she demonstrated remarkable progress during the module. I selected all of the four prospective biology teachers, two prospective Earth and Space science teachers, and one prospective physics teacher for post-instructional module interview. Therefore, I conducted one-on-one semi-structured interviews, after the instructional module, with seven purposefully selected participants. I collected all other data from all twelve participants. There were seven female and five male participants. The sample consisted of one sophomore, five juniors, three seniors, and three graduate students. I also collected biographical and background information. In addition to their past research experience, I wanted to know if they have taken any history and/or philosophy of science courses, see Table 4-1. Two participants had significant research experience; Lisa worked in a virology lab for two years. In addition to having open inquiry experiences during her undergraduate years, Mary has taught physics lab for two years. The other participants either never had research experiences or had very limited experiences during their undergraduate courses.
4.3.2 Data Sources and Sampling Criteria

Potential participants were prospective secondary science teachers enrolled in SCIED 410, *Technology Tools to Support Scientific Inquiry*, at the Pennsylvania State University during the spring semester of 2003. In most qualitative studies, participants are purposefully selected based on some criteria. According to Maxwell (1996), this is a strategy in which particular settings, people, or events are selected purposefully in order to provide significant information not available elsewhere. My previous research revealed

<table>
<thead>
<tr>
<th>Name</th>
<th>Class</th>
<th>Undergraduate Major</th>
<th>Past research experience</th>
<th>Hist. Sci. Course</th>
<th>Phil. Sci.</th>
<th>Biology Courses</th>
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<td>Animal Bioscience</td>
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<td>No</td>
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<td>No</td>
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<td>No</td>
<td>No</td>
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<td>Sec. Ed. / Biology</td>
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<td>M.Ed.</td>
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<td>John</td>
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<td>Sec. Ed. / Earth &amp; Space Science</td>
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<td>Mike</td>
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<tr>
<td>Kate</td>
<td>Junior</td>
<td>Sec. Ed. / Chemistry</td>
<td>None</td>
<td>No</td>
<td>No</td>
<td>One introductory</td>
</tr>
</tbody>
</table>

Sec. Ed: Secondary Education
* Boldface indicates focus participants who were interviewed
that prospective science teachers, including biology majors, do not have sound understanding of Mendelian genetics concepts (Çakir & Crawford, 2001). Therefore, I was especially interested in exploring prospective biology teachers’ understandings and compare and contrast them with prospective science teachers in other disciplines. Furthermore, purposeful sampling could provide information-rich cases from which researcher can learn great deal about issues relevant to the study (Patton, 1990).

The physical setting for the instructional module was a computer lab containing 16 microcomputers. One of the secondary sources of data was process videos. Process video entails videotaping a computer monitor while simultaneously recording participants’ conversations while interacting with the computer. I recorded process videos for selected four pairs of prospective science teachers while interacting with the computer simulation.

4.3.3 Procedures of Data Collection

Interviews are useful way to elicit information about how people feel and interpret the world around them (Merriam, 1998). A list of questions or issues to be explored guides the semi-structured interview approach. However, neither the order of the questions nor the exact wording is predetermined (Patton, 1990). This protocol was decided to be most appropriate for this study because of individual differences in understandings within the case. The interviews were semi-structured based in part on the participant’s interactions during the module and responses to the questionnaires for the purpose of member checking (Merriam, 1998; Miles & Huberman, 1994) and to provide an opportunity for a more detailed investigation into their understandings.
After administering the post-tests of scientific inquiry understandings and Mendelian genetics concepts to all of the participants, I studied the responses and made notes about points that needed clarification or elaboration. I conducted semi-structured interviews based in part on the prospective teachers’ responses to the questionnaires and where their interviews led the conversation. Interview transcripts, pre-tests, and post-tests of views of scientific inquiry (Appendix D), pre-tests, and post-tests of Mendelian genetics concepts, and inquiry project reports, and presentations were used as the primary source of data. Secondary supporting data consisted of videotapes of four pairs of prospective science teachers interacting with the computer simulation, homework assignments, and researcher’s journal. I collected data throughout the duration of the module, and interviews with selected participants were conducted after the instructional module. A summary of the design of the study and data sources is displayed in Table 4-2.

<table>
<thead>
<tr>
<th></th>
<th>VOSI &amp; Pre-instructional Genetics Survey</th>
<th>CATLAB Module</th>
<th>VOSI &amp; Mendelian Genetics Questionnaire</th>
</tr>
</thead>
<tbody>
<tr>
<td>Students’ background information</td>
<td>Inquiry project reports</td>
<td>Classroom Observation</td>
<td>Semi-structured Interview Protocol</td>
</tr>
<tr>
<td></td>
<td>Before</td>
<td>During</td>
<td>After</td>
</tr>
</tbody>
</table>
4.3.3.1 Paper-pencil Mendelian Genetics Concepts Test

In order to evaluate participants’ understandings of subject matter, pre-tests (Appendix B) and post-tests (Appendix C) of Mendelian concepts were administered. These tests were modified from the Simmons & Lunetta (1993) study which reported expert and novices problem solving behaviors in genetics while interacting with Catlab. The purpose of the first test was to probe the students' initial understandings when they started the module. The post Mendelian genetics concept test was administered at the end of the module and given to all participants. Participants were asked to provide extended responses to the questions in these tests, even for multiple choice items. Pre- and post-tests also served to triangulate methods of data gathering. Their responses to the questions in these tests proved to be a valuable form of data since the responses represent the progression of the students' understanding and learning in written form and in their own words.

4.3.3.2 Views of Scientific Inquiry Questionnaire

I administered the Views of Scientific Inquiry (VOSI) questionnaire at the beginning and at the end of the instruction to all twelve participants. Views of Scientific Inquiry Questionnaire (VOSI) was developed and validated by Schwartz, Lederman, & Thompson (2001). VOSI is designed to evaluate the following aspects of scientific inquiry: a) multiple natures of scientific methods; b) relationship between evidence and conclusion; c) possible alternative explanations, multiple interpretations; d) difference between data and evidence; e) presenting the data in a meaningful way and developing
logically consistent reasoning. Finally, see Table 4-3 for the summary of the research questions, data sources, and the methods data analysis.

<table>
<thead>
<tr>
<th>Research Questions</th>
<th>Data Sources</th>
<th>Data Transformation</th>
<th>Method of Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>What is the nature of prospective secondary science teachers’ understandings of scientific inquiry and in what ways do these understandings change after engagement in guided inquiry that includes constructing and testing hypotheses?</td>
<td>Post Interviews with 7 participants</td>
<td>Transcription of Interviews</td>
<td>Coding interviews and pre/post questionnaires of VOSI using constant comparative method</td>
</tr>
<tr>
<td></td>
<td>Pre/Post tests of VOSI &amp; Mendelian Genetics with all participants</td>
<td>Tables and graphs for pre/post tests responses for comparison purpose</td>
<td></td>
</tr>
<tr>
<td>What are prospective secondary science teachers’ understandings of Mendelian genetics and to what extent, if any, did participants develop understanding of Mendelian genetics concepts?</td>
<td>Pre/Post tests of VOSI &amp; Mendelian Genetics with all participants Final inquiry project reports</td>
<td>Tables and graphs for pre/post tests responses for comparison purpose</td>
<td>Evaluation of project reports using a rubric Coding final projects for evaluation</td>
</tr>
<tr>
<td>(a) From the participants’ perspective, what were the strategies and interactions in the module that contributed to understanding of scientific inquiry and Mendelian genetics, as well as the development of abilities to do scientific inquiry? (b) What were the participants’ intentions for using inquiry in their own classrooms?</td>
<td>Post Interviews with 7 participants Process videos of 4 pairs interaction with simulation during their inquiry project</td>
<td>Transcription of interviews Time stamping relevant episode in the process videos</td>
<td>Coding interviews using constant comparative method Narrative analysis of episodes during their interaction with the software</td>
</tr>
</tbody>
</table>
4.4 Process of Data Analysis

The analysis of qualitative data is a dynamic, intuitive, and creative process of inductive reasoning and thinking. Throughout analysis, I attempted to gain a deeper understanding of the data and to refine my interpretations. I relied on my firsthand experience with participants and data collection process during my interpretation of the data. After transcribing the interviews I imported all documents including pre- and post-tests and inquiry reports into a qualitative analysis program, NVivo. As qualitative data analysis software, NVivo is relatively simple to use. It is possible to import documents directly from a word processing package and code these documents easily on screen. Coding stripes can be made visible in the margins of documents so that the researcher can see which codes have been used where.

4.4.1 Coding Documents (Creating Nodes)

Interviews and pre- and post-tests of VOSI, pre- and post-tests of Mendelian genetics, and final inquiry project reports were analyzed using NVivo which allowed me to create a database, assign a code to a text, and generate various reports. Coding and categorizing the data has an important role in analysis. Codes are labels for units of meaning for the descriptive or inferential information in the data. Miles and Huberman (1994) point to two methods of creating codes. The first one is not having any pre-code until after collecting data, seeing how it functions, and determining the varieties. This is essentially the ‘grounded’ approach originally advocated by Glaser and Strauss (1967). The other method preferred by Miles and Huberman, is to create a provisional ‘start list’ of codes prior to fieldwork. That list comes from the conceptual framework, list of
research questions, hypotheses, problem areas, and key variables that the researcher brings to the study. After transcribing all seven interviews I started analysis with 20 sociological codes that I constructed after reviewing the related literature (American Association for the Advancement of Science, 1990, 1993; Bell et al., 1998; Chinn & Malhotra, 2002; Khan, 2002; National Research Council, 2000).

Coding is a reflective activity. During the analysis new codes emerged and I ended with a total of 81 codes. I then created categories in order to construct a conceptual scheme that explained the data. Examples of coding included the following: Statements referring to the scientific experiments were coded as experiment. Evidence of designing a test or considering methods of testing was coded as experimental design. And statements about scientists using previous research and constructing knowledge in collaborative groups were coded as social construction of knowledge. I grouped all codes into six conceptual categories: 1) understanding of scientific inquiry; 2) scientific inquiry process skills; 3) understanding of genetics; 4) value of the module; 5) inquiry based teaching; 6) role of the teacher. For example; the first category, understanding of scientific inquiry, included the following codes: data, evidence, experiment, experimental design, bias, features of inquiry, interpretation, nature of science, prior knowledge, resistance to change conceptions, scientific fact, scientific method, social construction of knowledge, theory-data coordination, theory-leadness of methods, and worldview. This clearly illustrates that coding involved not only premeditation but also reflective activity. During the analysis, codes change and develop; other codes flourish. The complete list of codes can be seen in Appendix H. In order to answer the research questions the six categories of codes synthesized into three main themes.
4.4.2 Grouping Codes into the Categories (Creating Trees)

The next step was to create categories in order to construct a conceptual scheme that explains the data. Categories are simply families of codes that relate to each other one way or another.

Qualitative data are textual, non-numerical, and unstructured. Coding and categorizing has a crucial role in the analyses of such data to organize and make sense of them. Researchers have discussed coding and categorizing in the context of data reduction, condensation, distillation, grouping, and classification. When researchers devise a category, they are making decisions about how to organize the data in ways which are useful for the analysis, and we have to take some account of how this category will ‘fit’ into this wider analytic context (Dey, 1993). Codes are links between locations in the data and sets of ideas, and they are in that sense heuristic devices, which enable the researcher to reflect on the data.

4.4.3 Searching Sorting and Assembling during Analysis Using NVivo

After coding the seven transcripts, twelve pre- and post-tests of VOSI, twelve pre- and post-tests of Mendelian genetics, and six final inquiry projects, I was able to take advantage of the search facility of NVivo and to generate extremely useful reports, which I could save and print. The ‘Document Coding Report’ pertained to a single interviewee and collected all the extracts from the interview under separate node headings. The ‘Node Coding Report’ related to individual nodes and assembled all the extracts from those interviews in which that node had been used to code data. Furthermore, I was able to generate the interview transcript with ‘coding stripes.’ This showed an entire interview in
Together the three above-mentioned reports proved to be enormously helpful. The three types of reports produced in NVivo helped to accomplish the searching, sorting, and assembling functions of qualitative analysis.

4.5 Researcher's Qualifications and Roles in the Study

I hold a bachelors’ degree in secondary biology education and master degrees in both science education and educational psychology. Moreover my main research interest
has been secondary and college level teaching and learning of biology. I have been an active participant and contributor in professional conferences (Çakir, 2003; Çakir & Carlsen, 2002; Çakir & Crawford, 2004a) and I have had extensive interactions with other researchers in science education and biology education. At the time of the data collection, I had completed the course work for the degree of Ph.D. in curriculum and instruction with an emphasis in science education. I have given special attention to History and Philosophy of Science and Psychological Foundations of Learning. Prior to the beginning of this study I was well informed about both qualitative and quantitative inquiry methods.

I have also conducted and presented a research study about prospective biology teachers’ conceptions of Mendelian genetics (Çakir & Crawford, 2001). In this study, besides designing the module, I acted as the instructor for the module and the researcher. This kind of involvement is not unusual in naturalistic inquiry. Merriam (1998, p. 203) emphasizes that researchers are the primary instrument of data collection and analysis in qualitative research by stating, "interpretations of reality are accessed directly through their observations and interviews.” Moreover, Steffe, Thompson, & Glasersfeld, (2000; as cited in Tasar, 2001) strongly encourages researcher's involvement as a teacher during investigation and views this dual role as a potential strength of a study rather than a weakness.

Therefore, my multiple roles in this study gave me access to deeper insights about the participants’ understandings and interactions with each other as well as with the computer simulation. I was co-instructor in the SCIED 410 course in fall 2002 and spring 2003 semesters. Prior to actual data collection, during fall 2002 semester I conducted a
pilot study to develop and refine the instructional module and primary data instruments. 

My involvement as a co-instructor in the course, gave me an opportunity to become acquainted and to develop good communications with the students. 

4.6 Validity Concerns in Qualitative Inquiry: Standards of Quality & Trustworthiness

Validity is a goal rather than a product; it is never something that can be proven or taken for granted. Validity is also relative: it has to be assessed in relationship to the purposes and circumstances of the research, rather than being a context-independent property of the methods or conclusions (Maxwell, 1996).

Debate on the usefulness of the concepts of validity and reliability in qualitative research has been undertaken for many years. According to Maxwell (1996) validity refers to the correctness or credibility of description, conclusion, explanation, interpretation, or other sort of account. The audio and video recording of observations and interviews, and verbatim transcription of these recordings were undertaken to ensure accuracy and completeness of description. It is important to interpret data for their meaning to the participants not as perceived by the researcher. The researcher acknowledges and understands that the main threat to valid interpretation is imposing one's own framework or meaning rather than understanding the perspective of the participants. Some researchers suggest that these terms are inappropriate in qualitative research. Nevertheless qualitative research and data analysis must be accomplished in a thorough and transparent manner.

In discussing standards of quality Maxwell (1996, p. 89) asserts that three types of understanding emerging from a study could introduce distinct threats to validity, namely descriptive, interpretive, and theoretical. According to Merriam (1998):
Concerns over trustworthiness can be approached through careful attention to a research’s conceptualization and the way in which the data were collected, analyzed, and interpreted and the way in which the findings presented.

An account of quality of findings in terms of credibility (internal validity), dependability (reliability), and transferability (external validity) is necessary (Maxwell, 1996). I will address these issues and how I took them into the consideration throughout my research study.

4.6.1 Credibility

Qualitative researchers have articulated several ways to ensure that research findings represent reality and make good sense (Creswell, 1998; Maxwell, 1996; Merriam, 1998; Miles & Huberman, 1994). Special attention should be given to the qualification of the researcher, rigors of data collection and analysis, data and researcher triangulations, and the theoretical beliefs that frame the study.

Previously in this chapter, data collection methods, role of the researcher, and the theoretical framework of the study were described in detail. I collected the data for this study in the most comprehensive way possible to make sure that subsequent analysis and interpretations rest on sound evidence. When transcribing interviews, I gave a sincere effort to accurately reflect the audio recordings.

Triangulation is a way to promote credibility; therefore I collected data from various sources by various methods. Triangulation can mean using multiple investigators, multiple sources of data, or multiple methods to confirm emerging findings (Merriam, 1998; Patton, 1990; Strauss & Corbin, 1998). Patton asserts that triangulation is a strategy for reducing systematic bias and can safeguard against the accusation that research
findings are a result of a single method, data source, or investigator bias. After providing a thorough review of qualitative inquiry literature Tasar (2001) devised check tables to address important aspects of internal and external validity and reliability. Table 4-4 presents Tasar’s (2001) questions associated with internal validity and the researcher's answers as they relate to this research.

<table>
<thead>
<tr>
<th>Table 4-4: Credibility Check</th>
</tr>
</thead>
<tbody>
<tr>
<td>Were the data collected properly?</td>
</tr>
<tr>
<td>Were the data sources triangulated?</td>
</tr>
<tr>
<td>Were the data collection methods triangulated?</td>
</tr>
<tr>
<td>Was a &quot;member checking&quot; strategy implemented during data collection?</td>
</tr>
<tr>
<td>Were the data thick, rich, and deep?</td>
</tr>
<tr>
<td>Were the data presented in its entirety?</td>
</tr>
<tr>
<td>Were all the available data analyzed?</td>
</tr>
<tr>
<td>Was any part of the data overlooked or discarded during analysis?</td>
</tr>
<tr>
<td>Were only the data that fitted the researcher’s theory or point of view selected?</td>
</tr>
<tr>
<td>Was a reality constructed as the researcher wanted to see it?</td>
</tr>
<tr>
<td>Was the researcher’s purpose to prove or disprove a theory?</td>
</tr>
<tr>
<td>Were the participants free to act and converse naturally throughout the study?</td>
</tr>
<tr>
<td>Were the participants constrained to act or respond in only certain ways throughout the study?</td>
</tr>
</tbody>
</table>

I compiled initial sociological codes from the relevant literature before starting to the first level of analysis which was exploration of interview transcripts. During the first level of analysis, I added new codes as they emerged from the data and generated initial categories and developed change-over-time themes. The emergent themes were revised and refined through constant comparative analysis (Glaser & Strauss, 1967).

4.6.2 Dependability

Dependability in qualitative inquiry corresponds to the reliability concept in traditional quantitative research. It refers to the extent to which research findings can be
replicated. Since creating the identical settings and finding same participants is never possible, establishing reliability in a traditional sense is problematic in qualitative inquiry. As an alternative to reliability Merriam (1998) proposed dependability or consistency that

Rather than demanding that outsiders get the same results, researcher wishes outsiders to concur that, given the data collected, the results make sense— they are consistent and dependable. The question then is not whether findings will be found again but whether the results are consistent with the data collected.

Therefore, the reliability question for qualitative inquiry becomes how well the procedures were documented throughout the study and how consistent were results with regard to the data that was collected (Merriam, 1998, p. 207; Yin, 1994, p. 36). Table 4-5 lists main concerns about dependability, consistency, (Tasar, 2001) and my answers as they relate to this study.

<table>
<thead>
<tr>
<th>Question</th>
<th>Answer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Were the data collection methods and instruments documented and described properly?</td>
<td>YES</td>
</tr>
<tr>
<td>Can an independent judge authenticate the findings by following the trail of the researcher?</td>
<td>YES</td>
</tr>
<tr>
<td>Will all such studies yield exactly the same results?</td>
<td>NO</td>
</tr>
<tr>
<td>Was there a researcher triangulation in the strict sense?</td>
<td>NO</td>
</tr>
<tr>
<td>Were the data sources triangulated?</td>
<td>YES</td>
</tr>
<tr>
<td>Were the methods of data collection triangulated?</td>
<td>YES</td>
</tr>
<tr>
<td>Are the results obtained from the data &quot;dependable&quot; and &quot;consistent&quot;?</td>
<td>YES</td>
</tr>
<tr>
<td>Was the theoretical framework behind this study explained clearly?</td>
<td>YES</td>
</tr>
<tr>
<td>Were the context and the characteristics of this study described adequately?</td>
<td>YES</td>
</tr>
</tbody>
</table>

Another way to ensure reliability of a qualitative study is via researcher triangulation – having more than one researcher present during data gathering and analysis. Although there was only one researcher involved in data gathering, I
collaborated with faculty and colleagues during data analysis. Collaborative research and feedback serve to reduce analysis error and improve the credibility of the study. After my invitation, two fellow doctoral candidates in our science education program and two post-doctoral fellows in other respected institutions agreed to code interview transcripts independently, and I have had a conversation with them on coding, categories, emerging themes, patterns, and discrepancies. I constantly shared developing insights with my thesis advisor and worked closely with her throughout all phases of this study.

I presented different aspects and results of this study in various international conferences. For example, at the Annual Meeting of the Association of Educating Teachers of Science focus of my presentation was the design of the module in this study (Çakir & Crawford, 2004a). I presented results regarding the prospective teachers’ understandings of scientific inquiry and Mendelian genetics along with their perceptions of the learning environment at the Annual Meeting of the National Association of Research in Science Teaching (Çakir & Crawford, 2004b). I also presented results about prospective teachers’ views of inquiry-based teaching and community of learners along with their intentions of implementing inquiry-based teaching practices in the future at the Annual Meeting of the American Educational Research Association (Çakir & Crawford, 2004c). All these experiences provided valuable feedback from the referees and colleagues from all over the U.S.

4.6.3 Transferability

The concept of transferability corresponds to the notion of generalizability, in other words, external validity, in quantitative research tradition. It is concerned with the
extent to which findings of a study can be applied to other situations. However, in contrast to most quantitative study, a qualitative study is preferred by the researchers because of the desire to achieve in-depth understanding of one situation.

Kvale (1996) discusses the analytical generalizability of results from interview-based studies. He emphasizes how the reader's judgments of the wider significance of a piece of research will depend both upon the detail of supporting evidence provided by the author of a report and upon the experiences the reader brings to the report. The detail in qualitative research reports allows the reader to make an informed comparison between the research context and other contexts where the findings might apply.

According to Merriam (1998)

Because what is studied in education is assumed to be in flux, multifaceted, and highly contextual, because information gathered is a function of who gives it and how skilled the researcher is at getting it, and because the emergent design of a qualitative case study precludes a priori controls, achieving reliability in the traditional sense is not only fanciful but impossible.

Therefore, to address generalization issues in qualitative research, the researcher must provide enough description so readers will be able to determine how closely their own situations reflect the research situation and the transferability of findings (Merriam, 1998). When findings are summarized into a hypothesis, model, or theory, a case study can become a vehicle for examining other cases (Yin, 1994). Taber (2000) suggests that case study findings should also be "tested" by "replication studies with other samples of learners." If working hypotheses driven from one case study endure the scrutiny of other researchers and various tests then they said to be corroborated. Table 4-6 lists several
concerns related to the notion of transferability and my answers as they relate to this study.

<table>
<thead>
<tr>
<th>Table 4-6: Transferability Check</th>
</tr>
</thead>
<tbody>
<tr>
<td>By their nature should the potential findings of this study be confined strictly to this case of learning only?</td>
</tr>
<tr>
<td>By its nature can this study potentially provide insights of wider value, i.e. is it relevant to wider contexts?</td>
</tr>
<tr>
<td>By their nature are the potential results of this study readily generalizable to all individual cases of learning?</td>
</tr>
<tr>
<td>By its nature can this study be replicated elsewhere in different institutions and/or in different education systems?</td>
</tr>
<tr>
<td>By their nature are, at least, certain aspects of potential findings of this study open to statistical testing and generalization?</td>
</tr>
<tr>
<td>Was a rich and vivid description of participants provided?</td>
</tr>
<tr>
<td>Was a rich and vivid description of the context of the study provided?</td>
</tr>
</tbody>
</table>

In sum, I have attempted to improve the quality of my study by addressing the procedures described above.

4.7 Summary

In this chapter, I explained methods and procedures of data collection in detail. In the next chapter I will present the findings and discussion of my data analysis as three main themes organized around the research questions.

I generated three themes to answer the research questions. The first theme was participants’ knowledge about scientific inquiry and their ability to do inquiry was created by combining the first and the second categories listed in section 4.4.1. The second theme, participants learning and knowledge about Mendelian genetics concept, was created by combining the third and the fourth categories. The third theme, participants’ perspectives of the learning environment and of inquiry-based teaching, was created by combining the fourth, the fifth, and the sixth categories.
Chapter 5

FINDINGS & DISCUSSION

In this chapter, I present findings of my analysis as three main themes organized around research questions. These themes have emerged from six categories of codes that are listed in Chapter 4. Namely, these categories are: 1) understanding of scientific inquiry; 2) scientific inquiry process skills; 3) understanding of genetics; 4) value of the module; 5) inquiry based teaching, and 6) role of the teacher. The complete list of codes within these categories is provided in Appendix H. I presented excerpts from data sources to support the interpretation that resulted from data analysis.

5.1 First Theme: Participants’ Knowledge about Scientific Inquiry and Their Ability to Do Inquiry

This first theme relates to the first research question: What is the nature of prospective secondary science teachers’ understandings of scientific inquiry and in what ways do their understandings change after engaging in guided inquiry that include constructing and testing hypotheses? Research findings suggest that prior to this experience, the prospective teachers held uninformed views of scientific inquiry and the nature of science. Following instruction, evidence suggested that the prospective teachers’ understandings of scientific inquiry and their abilities to do inquiry were enhanced. Initially, they viewed scientific inquiry as the posing of questions and investigation of them in order to learn the truths of science. They viewed science as a way of understanding nature and the world around them through use of the scientific method. They also viewed observation, exploration, and experimentation as a crucial part
of this process. Science was also seen as a tool to solve problems in our world and help us in our everyday lives. Prospective teachers began to recognize the elements of scientific inquiry and importance of data-driven evidence and use of models in science. Prospective science teachers demonstrated more informed understandings of several aspects of scientific inquiry and the nature of science after the module. Evidence of enhanced understandings included comparisons of pre- and post-tests of Views of Scientific Inquiry questionnaires and semi-structured interviews.

Although scientific inquiry and nature of science are separate constructs, there is an inevitable overlap, due to the type of knowledge being assessed. One important component relating to both inquiry and the nature of science is that scientific knowledge is tentative, being continually subject to change and revision. Tentativeness of scientific knowledge arises from the very process of science (a) knowledge has a basis in empirical evidence, (b) evidence is collected and interpreted based on current scientific theory-laden observations and interpretations as well as personal subjectivity due to scientists’ values, knowledge, and prior experiences, and (c) knowledge is the product of human imagination and creativity (Schwartz et al., 2001).

Pre- and post-VOSI analysis showed that participants developed more informed understandings of the following aspects of scientific inquiry: a) valid multiple interpretations of data (this aspect of scientific inquiry relates to interpretive, subjective, and tentative aspects of nature of science) b) distinctions between data and evidence; c) multiple methods of scientific investigations; d) importance of consistency between evidence and conclusions; e) data analysis as directed by research questions, involving multiple representations of data and the development of patterns and explanations that are
logically and conceptually consistent; f) social aspects of science, peer interaction, and the role of communication in the development and acceptance of scientific knowledge, and g) degree to which scientists rely on empirical data as well as broader conceptual and metaphysical commitments to assess models and to direct future inquiries.

5.1.1 Valid Multiple Interpretations of Data

Analysis of the pre-VOSI questionnaires revealed that most of the participants recognized that scientists working on the same problems may not reach the same conclusions, even if they use the same experimental procedures. Prospective teachers’ responses generally reflected an informed view. However, among the participants there were also uninformed and mixed views of this aspect of scientific inquiry. Only one participant, Lisa, said that if scientists followed the procedure correctly they should come up with the same conclusions. Other participants cited scientists’ background and prior knowledge, differences in interpretations, bias and personal values, assumptions, and theoretical commitments as potential bases of disagreements among scientists. A follow-up question was, “Would scientists change their answers if scientists were working together.” Except for Lisa, all of the other participants stated that even if scientists worked together, they still may not agree on conclusions. In post-VOSI all of the prospective science teachers demonstrated a firm understanding of the role of the interpretation, subjectivity, and creativity in science; they all recognized the role scientists’ backgrounds and worldviews play in data analysis. They were more articulate and their responses demonstrated more informed view of this particular aspect of
scientific inquiry. Quotes in Table 5-1 illustrate participants’ pre- and post-VOSI responses.

### Table 5-1: Pre- and Post-VOSI Responses on Valid Multiple Interpretations

<table>
<thead>
<tr>
<th>Name</th>
<th>Pre VOSI</th>
<th>Post VOSI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ashley</td>
<td>Scientists’ own educational background, research, methods, etc will vary and will result in different conclusions.</td>
<td>I* Even if they follow the same procedures to collect data, they will still have personal biases that will affect the outcome.</td>
</tr>
<tr>
<td>Ben</td>
<td>I No, they all still have to interpret the data and may see it differently.</td>
<td>I No, because they aren’t guaranteed to interpret that data in the same way.</td>
</tr>
<tr>
<td>John</td>
<td>I Scientists are influenced by their backgrounds, values, and biases.</td>
<td>I Scientists are humans and have their own personal biases and backgrounds which affect their interpretation of data.</td>
</tr>
<tr>
<td>Karen</td>
<td>PI Scientists’ backgrounds influence what they study. Each scientist would have a unique approach to the question.</td>
<td>I No, because their interpretations will be influenced by their backgrounds.</td>
</tr>
<tr>
<td>Kate</td>
<td>I The way they interpret findings will be unique to the individual.</td>
<td>I They make different judgment calls throughout their research.</td>
</tr>
<tr>
<td>Kevin</td>
<td>I Scientists can come up with unique explanations for why they accrued.</td>
<td>I Individually they might not agree. They will present the best explanation, but it is a compromise of different views.</td>
</tr>
<tr>
<td>Lisa</td>
<td>U They should have the same conclusions.</td>
<td>I Scientists are going to interpret data differently based on prior knowledge and/or experience.</td>
</tr>
<tr>
<td>Mary</td>
<td>I Not unless they are all making the same exact assumptions, using the same data/sights/computer programs.</td>
<td>I No because they’ll make certain assumptions.</td>
</tr>
<tr>
<td>Mike</td>
<td>I The amount of knowledge, resources, experience, and preceding notions can affect results of experiments.</td>
<td>I Each scientist interprets data in his own way, and finds some data to be more important than other data.</td>
</tr>
<tr>
<td>Rachel</td>
<td>PI It is entirely possible for a few of them to come to the same conclusion. But scientists have different prior knowledge about the subject and probably different ways of approaching and testing the question.</td>
<td>I No, each scientist could notice some things and not others, leading to the possibility of different conclusions.</td>
</tr>
<tr>
<td>Valerie</td>
<td>I No, even if all the data is the same, it still must filter through a very subjective human, who brings biases, beliefs, and prior knowledge to the table.</td>
<td>I They may approach it from different angles; such as natural history, archeological, etc.</td>
</tr>
<tr>
<td>Wilson</td>
<td>N/A</td>
<td>I Scientists will all be using different data and different methods of analyzing the data. Personal biases would also play a role.</td>
</tr>
</tbody>
</table>

* I: informed view; U: Uninformed view; PI: Partially informed view
Scientists are going to interpret data differently based on prior knowledge and/or experience (Lisa, Post-VOSI, line 88);

Even if they follow the same procedures to collect data, they will still have personal biases that will affect the outcome (Ashley, Post-VOSI, line 75).

Kevin’s response was similar and he also recognized the possibility of multiple valid explanations for data and the role of interpretation and subjectivity in science:

While they have the same data, they may still interpret it differently”; the conclusions are based on interpretation, which can be different even for the same data (Kevin, Post-VOSI, line 82).

Valerie referenced different theoretical perspectives that scientists may use during their research:

Because everyone has some type of personal bias they bring to an experiment; there are many different ways one can go about investigating something. Each person interprets data in his own way, and finds some data to be more important than other data; they may approach it from different angles; such as natural history, archeological, etc. likewise they may use very different methods (Valerie, post-VOSI, line 76).

In his interview Ben articulated the tentative nature of science by giving an example from his own experience in the Catlab inquiry project:

Models can always change, you can always gather new data and you throw out what you did earlier but you won't completely actually throw out everything you had, you look at it and say what did we do wrong well that isn't fitting or like all orange cats are tabby cats, they are automatically tabby, that just overrides it and there was nothing else that went against our model it was just that so we said (Interview, line 241).

One of the interview questions was as follows: Scientists agree that about 65 millions of years ago the dinosaurs became extinct. However, scientists disagree about what had caused this extinction. Why do you think they disagree even though they all have the same information? Participants’ answers to this question also reflected their understandings of multiple interpretations in science:
What you have is you have incomplete data, it’s like you’re given 4, 9 and 12, that’s what you’re given. . . you’re supposed to come up with a number sequence that gives you 4, 9 and 12, and in reality, there’s a lot of number sequences that will give you 4, 9 and 12. N squares plus n minus 1; there are a lot of things that will give you a number sequence like that. However, there’s just not enough data there. I think that’s the problem (Mary interview, line 128).

A geologist would say it’s this, or a climatologist would say this, I think it depends on what that person brings into it, what they were trained or what their interests were. I would say it’s the meteor that hit, but other people would say it’s all the flooding. I think it depends on personal backgrounds of people (Karen interview, line 162).

As reflected in above quotes, participants hold an informed understanding of multiple valid interpretations of data in science and the importance of the theoretical commitments and assumptions in data analysis process. Observations and inferences are theory-laden; therefore, multiple and subjective interpretations of data are inevitable. Interview question helped to elicit participants’ conceptions of subjectivity, inference, creativity, and the empirical nature of scientific inquiry.

### 5.1.2 Nature of Experiments

Responses in the pre-VOSI indicated that prospective science teachers’ definitions of experiments varied from a naïve uninformed view to a somewhat informed view. Most responses indicated that participants viewed experiments as following particular steps and that scientists conduct experiments to prove or disprove theories:

- Specific set of steps taken to support or refute a hypothesis for a specific goal (Valerie, pre-VOSI, line 27);

- When a position or belief is taken on a topic and steps are taken to test that belief (Kate, pre-VOSI, line 27);

- Stating something you believe to be true and then do a test of some kind to either prove or disprove your idea (Karen, pre-VOSI, line 27).
Some participants emphasized that experiments try to disprove rather than prove hypotheses, for instance; Rachel’s definition was:

. . . A test or series of tests and observations done to disprove a hypothesis (Pre-VOSI, line 27);

Similarly Kevin stated:

It is a way to test a hypothesis in order to prove it wrong (Pre-VOSI, line 25).

Following the module prospective teachers stated more informed views. They mentioned the use of controls, and they emphasized multiple processes, rather than a set of pre-determined steps:

It is a procedure that is performed to investigate scientific phenomena. This procedure does not necessarily have to follow a specific set of steps. Some experiments can be hands-on and often involve data analysis and working with peers. They often lead to conclusions or theories (Ashley, post-VOSI, line 21);

A controlled scenario created to test a hypothesis or answer a question. Many times experiments help to find patterns and correlations (John, post-VOSI, line 26);

Experiment is something where one controls a variable (as much as possible) or observes something and measures as many variables as possible then collects data and draws conclusions from the data (looking at trends, etc.) (Mary, post VOSI, line 29).

Scientific inquiry in a very general sense refers to the several systematic approaches used by scientists in order to answer research questions. Entering the module, numerous participants had uninformed view of experiments. That is, a fixed set of steps that all scientists follow when trying to answer scientific questions. After the module, in exit interviews, participants articulated the contemporary informed view that the research questions guide the approach and the approaches may vary within and across scientific disciplines.
5.1.3 Multiple Methods of Scientific Investigations

Analysis of the pre-VOSI revealed that the majority of the participants initially held positivist views of science. Eleven out of twelve participants stated that there was one scientific method. They had more informed views at the end of the module. Pre- and post-VOSI responses are listed in Table 5-2 for all participants.

Semi-structured interview transcriptions helped to describe participants’ views of what constitutes “scientific.” Interview question number 26 was about a bird study (see Appendix G.) Nearly all participants agreed that it was a scientific investigation because the person gathered data through observation and drew conclusions. However, it was not an experiment, because the person did not test any hypothesis. The following excerpts provide evidence for their developing understanding:

I think it was scientific in that he did collect a lot of different data and it was all observation; it was not an experiment, but it does not have to be an experiment to be scientific (Ben interview, line 170);

It’s definitely scientific, but I don’t really think this is an experiment. So it’s scientific in that he saw these things and he kind of hypothesized (Karen interview, line 180);

I think it is scientific investigation. Because person made and observation about something he was interested in and a question popped on his mind, “Is there a relationship there?” Although he followed the scientific process in his thinking I think he needs to test and elaborate on his observation. You can make claims easily so, you need to test it (Kevin interview, line 115);

I say the investigation is definitely scientific, because a lot of science is an observational data that is how you learn in science, you link things together, I would not call it an experiment, because he just observed (Wilson interview, line 168).

The aspects of scientific inquiry are closely related. Participants’ views about experiments and multiple interpretations directly related their views of scientific
methods. Although, in the beginning, some of the participants showed more informed understandings about experiments and multiple interpretations they still believed there is one scientific method. Inconsistencies in participants’ understandings disappeared when they made connections between aspects of scientific inquiry and developed more informed understanding of all aspects of scientific inquiry.

5.1.4 Distinction between Data and Evidence

Prospective teacher’s understandings’ of data, evidence, and data analysis were more articulate at the end of the module. In the beginning, some of them had informed understandings of data and evidence, yet most of them demonstrated some confusion or uninformed understandings. When they were asked about data, difference between data and evidence, and data analysis, most of them demonstrated informed views of these concepts in the beginning. A typical response associated data with only numbers and data analysis with mathematics and statistics.

Half of the participants were aware of the difference between data and evidence in the beginning. However, in the post-tests, all of them were able to further articulate the difference, referencing the analysis process and building an argument for the results and conclusions.
<table>
<thead>
<tr>
<th>Name</th>
<th>Pretest</th>
<th>Posttest</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ashley</td>
<td>It is scientific because it included the steps of a scientific experiment, such as taking an idea and hypothesizing about it. No, there is more than one scientific method to science. Sometimes science can be completely “accidental.”</td>
<td>There is no one set of steps that scientists follow as they go about their work. Instead, there are a variety of different activities that they do to learn about natural world. No, there is more than one scientific method to science.</td>
</tr>
<tr>
<td>Ben</td>
<td>There is one scientific method to science: 1. Observe 2. Hypothesize 3. Experiment 4. Analyze results</td>
<td>No, there is more than one scientific method to science. Mendel’s experiments, setting up crosses and measuring traits vs. Observation of seismic waves. They are different in that one is a controlled experiment and the other is observations of natural processes. They are both scientific.</td>
</tr>
<tr>
<td>John</td>
<td>Yes, there is one scientific method to science. I think there are many ways to go about experimenting scientifically, but overall, they all come down to making observations, asking questions about these observations, making a hypothesis, then testing the hypothesis (over and over) to make conclusions.</td>
<td>No, there is more than one scientific method to science. Different kind of questions requires different sets of steps. But general idea is the same: trying to support or disprove an idea but the steps to answer the question may be different along the way</td>
</tr>
<tr>
<td>Karen</td>
<td>Yes, there is one scientific method to science. 1. Observe 2. Make a hypothesis 3. Test that hypothesis 4. Gather data 5. Do statistical test 6. Compare your data with previous experiments.</td>
<td>No, there is more than one scientific method to science. An experiment can be done by the standard methods: hypothesis; data; results; conclusions. Another way to do this experiment is just make observations and predictions without developing an actual experiment</td>
</tr>
<tr>
<td>Kevin</td>
<td>Yes, there is one scientific method to science. Science starts with an observation. Next a question must be made. Then a hypothesis should be made to try to answer your question. Next we design a test to see if our hypothesis is wrong.</td>
<td>No, there is more than one scientific method to science. You can observe, hypothesize, design an experiment, and then draw conclusions or you could make a statement or theory an then run tests to collect data for support or to disprove the theory.</td>
</tr>
<tr>
<td>Mary</td>
<td>No, there is more than one scientific method to science. A hypothesis is needed for all methods, but sometimes there are very different steps between hypothesis and conclusions.</td>
<td>No, there is more than one scientific method to science. Someone gets out and observes bird population and other factors (temp, characteristics of birds…) that might be causing fluctuations in the population. The scientist collects the data and then makes inferences from it. This is scientific. An engineer designs a new processor, s/he then tests the chip to determine if it is better then the last chip.</td>
</tr>
<tr>
<td>Name</td>
<td>Pretest</td>
<td>Posttest</td>
</tr>
<tr>
<td>-------</td>
<td>-------------------------------------------------------------------------</td>
<td>-------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Rachel</td>
<td>Yes, there is one scientific method (set of steps) to science: form a</td>
<td>No, there is more than one scientific method to science. One method</td>
</tr>
<tr>
<td></td>
<td>hypothesis; research the topic; come up with a way to test the</td>
<td>may use rigorous experiments to reach an answer; one method may use</td>
</tr>
<tr>
<td></td>
<td>hypothesis; test and observe; reformulate hypothesis and repeat</td>
<td>simple observations to reach an answer.</td>
</tr>
<tr>
<td></td>
<td>cycle.</td>
<td></td>
</tr>
<tr>
<td>Mike</td>
<td>Yes, there is one scientific method to science: Raise an idea for</td>
<td>There is no yes or no answer to this question. I think that while</td>
</tr>
<tr>
<td></td>
<td>investigation; consider why the idea should be investigated, how, and</td>
<td>scientists do not always take the same approach to an investigation,</td>
</tr>
<tr>
<td></td>
<td>what is expected; devise a way to clearly test or investigated your</td>
<td>they all go through the same motions (in a different manner and</td>
</tr>
<tr>
<td></td>
<td>idea; gather data from your experiment; consider your results;</td>
<td>different order), but still in the end use these following</td>
</tr>
<tr>
<td></td>
<td>reinvestigate idea and compare results.</td>
<td>techniques at one point or another. Scientists observe, evaluate</td>
</tr>
<tr>
<td></td>
<td></td>
<td>experiment, predict, hypothesize, relate, test, work with data, and</td>
</tr>
<tr>
<td></td>
<td></td>
<td>learn.</td>
</tr>
<tr>
<td>Valerie</td>
<td>Yes, there is one scientific method to science. While there are</td>
<td>No, there is more than one scientific method to science. Obviously</td>
</tr>
<tr>
<td></td>
<td>variations, all experiments follow roughly: 1. research the topic to</td>
<td>there is the straight scientific method way: research, pose a question,</td>
</tr>
<tr>
<td></td>
<td>be experimented 2. form a hypothesis 3. construct an experiment to</td>
<td>make a hypothesis, experiment, and evaluate results. In addition,</td>
</tr>
<tr>
<td></td>
<td>test the hypothesis 4. perform the experiment 5. collect data 6.</td>
<td>scientific research can be done simply by observation. That is often</td>
</tr>
<tr>
<td></td>
<td>analyze data to see if it supports or refute the hypothesis 7. test</td>
<td>scientists study animals by watching them in their natural environment</td>
</tr>
<tr>
<td></td>
<td>again.</td>
<td>and record their observation.</td>
</tr>
<tr>
<td>Kate</td>
<td>Almost all simple science fair projects have a five step method they</td>
<td>Yes, there is one scientific method to science. Formulate a question</td>
</tr>
<tr>
<td></td>
<td>follow. It gives the kids a more structured way of performing</td>
<td>and try to answer the question.</td>
</tr>
<tr>
<td></td>
<td>experiments.</td>
<td></td>
</tr>
<tr>
<td>Lisa</td>
<td>Yes, there is one scientific method: Collect data, Hypothesis,</td>
<td>No, there is more than one scientific method to science.</td>
</tr>
<tr>
<td></td>
<td>Carrying out an experiment, Results, Conclusions, Repeatability.</td>
<td></td>
</tr>
</tbody>
</table>

*: U: Uninformed view; I: Informed view; PI: Partially informed view
Representative examples include the following:

Initially, Ben defined data as: “A set of known facts” (Pre-VOSI, line 117).

Valerie’s definition of data was: “Information, the numbers, measurement, and raw untouched results of an experiment or observation” (Pre-VOSI, line 94).

Similarly Mary responded: “Numbers, observations etc. that are used to prove or disprove a hypothesis” (Pre-VOSI, line 109).

Mike and Kate confused data with findings and results. Mike’s response was: “Results or information in general” (Pre-VOSI, line 111). Similarly Kate wrote: “Findings gathered from experiments or literary sources” (Pre-VOSI, line 102).

Nearly all participants showed more informed understandings of data in post-test; however some participants still focused on the numerical nature of data. For example, Ben’s definition of data changed as: “A set of gathered information “(Post-VOSI, line 118).

The following quotes provide evidence of change:

Data is the information gathered/collected during an investigation (Lisa, post-VOSI, line 111).

Data is empirical evidence that is collected or obtained that can be analyzed to form conclusions about where the data came from (Kevin, post-VOSI, line 114).

Data is a general term for information. Does not have to be but is usually numerical (Mike, post-VOSI, line 112).

Data are the numbers, figures, calculations, and measurements (John, post-VOSI, line 115).

Data is used in science to support or disprove a theory. Data can be anything that is observed and recorded, either during an experiment or just during observation and investigation (Ashley, post-VOSI, line 83).
As stated earlier, some participants had an informed understanding about the difference between data and evidence at the beginning. For instance, John stated:

Evidence comes from data. Data are just pieces. You have to put them together and interpret them to form evidence (Pre-VOSI, line 111).

Rachel and Valerie similarly stated respectively:

By definition I think evidence is data that proves something one way or another, data is just information waiting to be interpreted (Rachel, pre-VOSI, line 121).

Evidence is data that has been interpreted (Valerie, pre-VOSI, line 99).

Ben also had informed understanding evident in his statement:

Evidence is normally used as a term describing data that increases the likelihood of something being or not being true (Pre-VOSI, line 122).

On the other hand others had uninformed understandings. For example, Mike said: “I would consider data and evidence to be one in the same” (Pre-VOSI, line 116) and Karen stated: “Evidence is something you look for before you conduct the experiment to help you write your hypothesis” (Pre-VOSI, line 119).

While distinguishing between data and evidence Lisa and Kate could not articulate the difference stating

Data is not the same as evidence. If you can repeat your data and others repeat your data then your data can be used for evidence (Lisa, pre-VOSI, line 112).

I would say different. Evidence can be more opinionated and pervasive (Kate, pre-VOSI, line 107).

The post-test indicated that all participants acquired an informed view of the difference between data and evidence. For example, Mike, Karen, Lisa, and Kate gained a more informed understandings, as we can see in the following quotes:
Data can serve as evidence or data can support or deny existing evidence (Mike, post-VOSI, line 118).

Evidence is something that constitutes proof. Data can lead to evidence (Karen, post-VOSI, line 119).

Evidence indicates support for or against. Some data is just for consistency (Kate, post-VOSI, line 120).

Data may not be evidence but evidence comes from data. So some data may not be evidence for the test you are conducting (Lisa, post-VOSI, line 116).

Those who had initial informed understandings to begin with were able to further articulate their views. For instance:

Data is row, evidence is data that has been analyzed and is used to support as disprove a hypothesis (Ben, post-VOSI, line 123).

Data is un-interpreted. Evidence must be interpreted (Valerie, post-VOSI, line 98).

Initially, most participants recognized a difference between data and evidence; however a majority of them could not articulate the difference. Generally they associated data with numbers and measurements and evidence with proof.

5.1.5 Data Analysis

When asked about data analysis, most of the prospective teachers initially mentioned making calculations, statistics tests, and making sense of numbers. Yet they were not able to specify what data analysis comprised:

Data analysis is using statistical tests to analyze your data (Karen, pre-VOSI, line 124).

Making sense of numbers/observations finding trends, percents etc., usually it involves a lot of Excel work (Mary, pre-VOSI, line 119).
Data analysis is a process of taking nonsensical numbers and measurements and making some practical sense of them. It involves asking, “Why?” (Valerie, pre-VOSI, line 104).

The interpretation of data, it mostly involves calculations like seeing whether numerical data fits into one standard deviation of the expected (Ben, pre-VOSI, line 127).

In post-VOSI questionnaires, prospective science teachers explained data analysis as a process of examining the data, looking for patterns, comparing and contrasting, and seeking for an explanation for the problem using critical thinking.

Data analysis is the process of looking over the data that has been collected and making conclusions based on that data, includes using mathematics, methods of comparing or contrasting data, drawing conclusions about the data (Ashley, post-VOSI, line 91).

It could involve mathematics, comparison with other data, noticing a pattern (Ben, post-VOSI, line 128).

Looking at the data you collected critically and seeing if there is a relationship. It involves critical thinking, exploring relationship, looking at graphs, talking with other scientists (Karen, post-VOSI, line 124).

Data analysis is studying and interpreting data; making connections and looking for answers (Mike, post-VOSI, line 124).

Data analysis is interpreting what a set of data means. Interpretation of what trends are seen in data and why these trends occur (Wilson, post-VOSI, line 131).

Prospective science teachers became aware of the importance of the research questions, procedures, and the theoretical lenses in the process of data analysis. Data analysis cannot be done without guidance from the purpose of the research. All aspects of scientific inquiry are very closely knit together and the holistic view should be communicated to learners in science classrooms.
5.1.5.1 Empirical Aspects of Science

Interview responses highlighted the difference between inquiry in science and inquiry in other disciplines, such as philosophy and religion. All participants emphasized the empirical aspects of science:

Scientific knowledge is more reliable because of supporting data and evidence, in science things are tested many times before they are accepted as a general knowledge so most people have pretty good faith that those experiments were done well and data is correct (Rachel, line 96).

Scientists use logic and evidence; they apply the logic to the evidence (Ben interview, line 226).

In science there are facts and knowledge you can see on the table and you can go into inquiry looking at the data and interpret it and come up with a conclusion that you can prove over and over again (Wilson interview, line 152).

5.1.6 Social Aspects of Science

The most consistent responses in the questions concerned the social aspects of science, peer interaction, and worldview of scientists. For example, when participants were asked “If scientists, working independently, ask the same question and follow the same procedures to collect data, will they come to the same conclusions? All participants responded “No” and articulated several reasons. For example Ashley, John, and Wilson stated that since scientists have different worldviews and biases their interpretation of the data would be different:

Even if they follow the same procedures, they will still have personal biases. Biases and personal feelings can influence what material scientists study and the conclusions they reach (Ashley, post-VOSI, line 75).

They are influenced by their own knowledge and backgrounds. They have biases just like everyone else. They are influenced by their values as well as things that are going on in the world (John, post-VOSI, line 20).
No, because the scientists will be using different data and different methods of analyzing the data. Personal biases would also play a role (Wilson, post-VOSI, line 96).

Similarly Mary, Mike, and Valerie drew attention to theoretical commitments and assumptions that are inherent in scientific investigations. They also mentioned the different theoretical perspectives that scientists in different fields would use to evaluate data on the same matter:

Unless they are all making the same exact assumptions, using the same data/sights/computer programs/equipment, they probably will get similar but not identical answers (Mary, post-VOSI, line 91).

There are many different ways one can go about investigating something. Each person interprets data in his own way, finds some data to be more important than other data (Mike, post-VOSI, line 89).

No, they may attack it from very different angles and using very different means. One may look from an archeological standpoint, another geological and yet another biological (Valerie, post-VOSI, line 76).

While they have the same data, they may still interpret it differently; the conclusions are based on interpretation, which can be different even for the same data (Kevin, post-VOSI, line 82).

During interviews Rachel and Mary emphasized the subjectivity in science and how scientists discount some data:

There is no way to separate subjectivity out of science. People approach anything they do with past experiences they cannot close out everything all they prior knowledge when they are researching (Rachel, line 104).

But data is subjective, you can discount evidence, you can say, “Oh, we’re not going to take that evidence because it was taken in Arizona, and we just aren’t including Arizona in this study.” People do that all the time (Mary, line 143).

According to participants, scientists’ activities included developing hypotheses, experimenting, collecting data, and collaborating, debating, modeling, building upon and may perhaps even change previously accepted facts, publishing. Participants listed
personal interest, needs of society, funding, job requirements, ambition, political factors, ethics, and religion as the factors that influence what scientists study.

### 5.1.7 Defining Scientific Inquiry

In their final interviews, I asked prospective teachers to define scientific inquiry.

Their definitions demonstrated a range of understandings. Table 5-3 lists their definitions of scientific inquiry.

<table>
<thead>
<tr>
<th>Table 5-3: Prospective Teachers’ Definitions of Scientific Inquiry</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Ben</strong></td>
</tr>
<tr>
<td><strong>Mary</strong></td>
</tr>
<tr>
<td><strong>Kevin</strong></td>
</tr>
<tr>
<td><strong>Wilson</strong></td>
</tr>
<tr>
<td><strong>Karen</strong></td>
</tr>
<tr>
<td><strong>Lisa</strong></td>
</tr>
<tr>
<td><strong>Rachel</strong></td>
</tr>
</tbody>
</table>
Prospective science teachers emphasized different aspects in their definitions of scientific inquiry. On the one hand, Mary, Wilson, and Lisa stressed using an inquiry approach in teaching and having students engage in inquiry activities, in order to promote more meaningful learning and critical thinking. In particular, Wilson perceived scientific inquiry as a teaching method. On the other hand, Ben, Kevin, Karen, and Rachel defined the process of scientific inquiry as a way of problem solving in science without any reference to teaching and learning. While we want to inform our prospective teachers about important aspects of scientific inquiry, we also want them to be able to differentiate between scientific inquiry in science and inquiry-based teaching in science classrooms. This is an important issue that needs further exploration.

Although their definitions of scientific inquiry did not reflect completely informed views, they articulated several features of scientific inquiry. In analyzing their articulated definitions and features participants, demonstrated informed views of scientific inquiry. When I asked participants why they thought the Catlab module was inquiry based, they responded:

Well, we started with a question, we had to do our own investigation using the program to come up with the answers to every question we had in mind. Eventually we came up with an organized pattern of data collection. We definitely took a lot of data and recorded it, and collaborated with other groups. We come up with an explanation, so I think we did engage in inquiry activity (Rachel Interview, line 23).

Yes, because we were always revising our hypothesis and we were always constantly changing and generating ideas and checking those out; so it was definitely a scientific process (Lisa interview, line 80).

You analyze the data and try to come up with explanations based on that data that could change new data comes to the surface disproving yours and you just take that new data and try to come up with new explanation (Ben interview, line 38).
They emphasized the processes involved in inquiry and social interactions while doing inquiry. The following aspects were cited in interviews: peer interaction, communication, data collection, and analysis, constructing explanatory models, testing those models, generating follow-up questions, critical thinking, and considering alternative hypotheses.

There is a wide agreement among philosophers of science that because the practice of science is a human endeavor, it is by definition, inherently value laden and is influenced by social, political, and economical factors (Hodson, 1988). It is encouraging that participants in this study appeared to share an emerging philosophical view of scientific inquiry.

Prospective science teachers determined they had (a) generated scientifically oriented questions; (b) decided what evidence was needed; (c) collected and analyzed data; (d) formed explanations based on their evidence; (e) supported or adjusted their explanations based on scientific ideas, and (f) communicated and justified their conclusions in the presentations to their peers.

5.1.8 Changes in Views of Scientific Inquiry

I generated comparisons among all participants’ views of aspects of scientific inquiry before and after the module. Table 5-4 illustrates these comparisons. For each participant I assigned a letter for each aspect to represent change in their views. If there were major changes from misconception to informed view I assigned letter M. Similarly if they had an adequate view in the beginning and they demonstrated more informed views at the end I assigned letter E. If no change was evident in the data then I used
double hyphen (--) I used X to indicate that participants presented examples from their current or prior experiences. And, finally if they demonstrated making connections among aspects I assigned letter C. Finally I categorized the participants’ final understandings for each aspect as informed, partially informed, and uninformed.
Table 5-4: Change in Views of Aspects of Scientific Inquiry and Nature of Science

<table>
<thead>
<tr>
<th>Name</th>
<th>Multiple Interpretations</th>
<th>Conceptions of Data &amp; Evidence</th>
<th>Multiple Methods</th>
<th>Nature of Experiments</th>
<th>Process of Data Analysis</th>
<th>Social Aspects of Science</th>
<th>Nature of Science</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ashley</td>
<td>E C</td>
<td>E X</td>
<td>M C</td>
<td>E X</td>
<td>E X</td>
<td>E C X</td>
<td>E C</td>
</tr>
<tr>
<td>Ben</td>
<td>C X</td>
<td>M C</td>
<td>M X</td>
<td>E</td>
<td>E</td>
<td>E C X</td>
<td>E C X</td>
</tr>
<tr>
<td>John</td>
<td>--</td>
<td>--</td>
<td>M C</td>
<td>E X</td>
<td>--</td>
<td>E C X</td>
<td>E X</td>
</tr>
<tr>
<td>Karen</td>
<td>E</td>
<td>M C</td>
<td>M C</td>
<td>M</td>
<td>E</td>
<td>E C X</td>
<td>M C</td>
</tr>
<tr>
<td>Kate</td>
<td>--</td>
<td>M</td>
<td>--</td>
<td>M</td>
<td>E X</td>
<td>E C X</td>
<td>E C C</td>
</tr>
<tr>
<td>Kevin</td>
<td>E C</td>
<td>E C X</td>
<td>M C X</td>
<td>E C</td>
<td>E X</td>
<td>E C X</td>
<td>E C X</td>
</tr>
<tr>
<td>Lisa</td>
<td>M</td>
<td>M C</td>
<td>C</td>
<td>E X</td>
<td>E C</td>
<td>E C X</td>
<td>M C</td>
</tr>
<tr>
<td>Mary</td>
<td>--</td>
<td>E X</td>
<td>C X</td>
<td>C X</td>
<td>--</td>
<td>E C X</td>
<td>E C X</td>
</tr>
<tr>
<td>Mike</td>
<td>C X</td>
<td>M C</td>
<td>C</td>
<td>--</td>
<td>E</td>
<td>E C X</td>
<td>M X</td>
</tr>
<tr>
<td>Rachel</td>
<td>E</td>
<td>E C</td>
<td>M C X</td>
<td>E</td>
<td>--</td>
<td>E C X</td>
<td>E X</td>
</tr>
<tr>
<td>Valerie</td>
<td>C</td>
<td>E C X</td>
<td>M</td>
<td>M X</td>
<td>E</td>
<td>E C X</td>
<td>E C</td>
</tr>
<tr>
<td>Wilson</td>
<td>--</td>
<td>E C</td>
<td>E C</td>
<td>E</td>
<td>E</td>
<td>E C X</td>
<td>E C</td>
</tr>
</tbody>
</table>

Normal font denotes informed view, italic red font denotes partially informed view, and bold face denotes uninformed view.

M: Major change from uninformed to informed view
E: Enhanced (started out adequate, but gained)
X: Presented Examples from current or prior research settings
C: Showed connections among aspects
--: No change evident
5.1.9 Developing Abilities of Inquiry

The videotapes of pair discussions, as the pairs worked using Catlab, provided evidence of each pair’s problem solving behaviors. I selected 4 pairs for videotaping. Videotapes were not transcribed. Instead I used the videotapes as supplemental data sources to support my classroom observations and to confirm or refute participants’ self reports during final interviews. I used the final project reports and videotapes along with my classroom observations and interviews for this analysis.

In addition to learning about scientific inquiry, nature of science, and Mendelian genetics participants demonstrated evidence for developing inquiry process skills throughout the module. Inquiry and the National Science Education Standards (2000) lists the inquiry abilities that students are expected to develop by the end of the 12th grade. Such abilities include:

- Identifying questions and concepts that guide scientific investigations
- Designing and conducting scientific investigations
- Using appropriate tools and techniques to gather, analyze, and interpret data
- Developing descriptions, explanations, predictions, and models using evidence
- Recognizing and analyze alternative explanations and models
- Formulating and revising scientific explanations and models using logic and evidence
- Communicating and defending a scientific argument.
I used the multiple data sets mentioned above to trace participants developing inquiry skills. During the interview coding process, when participants illustrated evidence of evaluating quantitative or qualitative relationships, I coded that text for empirical consistency. Successful participants were able to incorporate more such skills than the less and the least successful participants.

Kevin and I came up with the slogan that we were going to try as hard as we could to prove ourselves wrong (Ben interview, line 26).

We would come up with a hypothesis and we make a prediction of what would happen based on hypothesis and we do couple crosses to see if they fit that prediction, and agree with the hypothesis (Ben interview, line 50).

After experiencing inquiry learning in this module participants thought if they engaged in another scientific inquiry, they would perform better and they would be less frustrated.

I would do it better. I saw a structure of how to do inquiry, opening with a driving questions and seeing it more and seeing how the vagueness eventually led to clues which eventually led to the process which after going through you understand what you have to be incorporating into each step of your inquiry (Wilson interview, line 110).

Successful participants also had a sound understanding of the importance of sample size and the probabilistic nature of gamete combination. Mary had degrees in physics and mathematics. Although Mary did not have a biology background, she was very quick in understanding basic Mendelian genetics and the underlying mechanisms of crosses.

I realized, to get a big enough sample, you have to get at least 30 cats, and if you’re looking for a very odd mix, if you have a 16 by 4 by 4, which gives you sixteen different possibilities, you need a hundred cats, and I think people were confused because they weren’t seeing stuff. I was like, “If you mate them 10 more times, you’ll get something out.” Once you get down to it, genetics is all about looking for patterns. It’s all mathematics.
It’s all matrices. So if you just think about them, at matrices, it’s like, “Oh, well it should be 4 to 3 to 2, or a 2 to 9 to 6, type 1 or whatever.” And you can figure out what the patterns should be, very quickly. It’s just pattern math, really (Mary interview, line 17).

Participants’ approaches to the task included the processes of generating qualitative and quantitative relationships between traits, evaluating the empirical consistency of the relations between genes by examining phenotypes of the offspring, and modifying these relationships according to interpretation of the data gathered. In addition, participants encountered discrepant information in Catlab and expressed their surprise when they discovered a particular relationship was not valid. Participants were observed designing a new test based on discrepant information to confirm their findings.

The transcript evidence suggested that each pair of participants engaged in multiple inquiry processes as they worked in the Catlab project. For example, I observed one pair generating a quantitative relationship that predicted a 3:1 ratio in phenotypes of the offspring. After evaluating the empirical consistency of the relationship for different parents, they modified their initial relationship to suggest that there is 2:1 ratio in phenotypes. They generated an explanatory model to answer a “Why?” question from the teacher and the peers and modified the original relationship by incorporating a lethal gene concept into the model. After that they were able to explain why the simulation generated 2:1 ratio instead of the expected 3:1.

In addition to engaging in fundamental processes commonly associated with scientific inquiry, participants also engaged in more complex processes, such as coordinating data with theory. One pair encountered disconfirming information, and the pair attempted to coordinate this new information with their hypotheses on gene
interactions. They postulated a hidden causal factor to explain discrepant information, and used analogies to support explanatory models. Selecting and reselecting variables and comparing phenotypes of F1 and F2 generation offspring may have had some implications for evaluating consistency of the relationship across cases. In addition selecting extremes may have encouraged “what if” scenarios that also helped learners to evaluate the consistency of the relationship. Therefore, there was ample evidence that working with Catlab enabled participants to evaluate and modify hypotheses.

At the beginning of the module I handed out a secondary science inquiry scoring guide, which was developed by the Northwestern Regional Educational Laboratory Mathematics and Science Education Center. My intention was to show the expectations for the inquiry projects and to provide a guideline. The inquiry scoring guide evaluates participants’ scientific inquiry abilities under four categories from “No evidence” to “Developing” to “Proficient” and finally to “Exemplary.” (See Appendix F, for four categories and the complete rubric.) Using the scoring guide, all participants demonstrated scientific inquiry abilities to some degree. After assessing the participants’ performance in the classroom, their project reports, final presentations, and interviews, I placed the participants into three groups as defined by the inquiry scoring guide: First group, successful, conducted and carried out exemplary investigations and demonstrated understandings of concepts and processes involved. Second group of participants, less successful, were proficient in their investigations. And, the third group, the least successful of participants, demonstrated developing abilities of scientific and understandings of processes.
Analyses of the general strategies which participants used to test their hypotheses revealed that the three groups used different problem solving approaches. For example, Ben, Kevin, and Mary tested all three possible phenotype combinations of cats (dominant x dominant, dominant x recessive, recessive x recessive). The other participants tested only one or two of the possible phenotype combinations. Some participants randomly crossed cats with no apparent system, and they changed more than one variable at a time during their crosses. Several participants generated three or four litters of kittens, upon which they based their inferences about inheritance patterns of traits. One participant crossed the same parents ten times before generalizing about the inheritance pattern and inferred the genotypes of the parents.

The following problem solving sequence was identified from participants’ interactions with Catlab during the inquiry project and from their final reports.

- Gathering data
- Describing qualitative observations
- Describing quantitative observations
- Drawing a conclusion
- Explaining a qualitative relationship
- Explaining a quantitative relationship
- Selecting an action
- Predicting
- Testing a prediction

5.1.9.1 Successful Participants

The successful participants used a systematic approach in their investigations, and they provided valid scientific reasons and explanations to justify their arguments. These
participants not only performed better on the post-test, but they also accomplished more in their inquiry projects using all of the following categories of crosses: P x P (parent with parent); F1 x F1 (offspring from first generation); F x P (offspring from the first, second, or third generations with a parent); F2 x F2 (offspring from second generation).

Typically these participants, Ben, Kevin, Mary, Ashley, and Wilson, were successfully able to conceptualize and apply basic genetics principles to hypothesis testing situations by making predictions about inheritance patterns, testing their predictions, and supporting their decisions by taking all possible occurrences into account. These participants consistently changed their incorrect pre-test responses to correct post-test responses. Yet even these successful participants were troubled with the probabilistic nature of the Punnett square.

Successful participants controlled variables related to their investigations and ignored other variables, when they were not related to their questions:

Instead of looking at it as a whole picture, we tried to break it down to the most basic question we could find and answer it and hope these answers to the little questions would give us clues to the answer for the ultimate question (Kevin Interview, line 28).

We saw that males couldn’t be bi-colored we knew that color had to be sex-linked, period. The minute we saw that you couldn’t get a solid-orange cat, we knew there was something weird with orange and we didn’t want to orange. We were like “we don’t want to do orange so we’re pretty much going to ignore it” (Mary interview, line 103).

Recognizing that Catlab assigns valid genotypes for selected cats randomly, one cannot know if a cat is homozygous or heterozygous for dominant trait. Successful participants bred heterozygous parents in F1 generation and then continued their investigations by using cats with known genotypes.
5.1.9.2 Less Successful Participants

Less successful participants, Rachel, Karen, John, Valerie, incorporated less systemic procedures into their hypotheses testing tasks than successful participants. They did not provide valid scientific explanations as thoroughly as successful participants. They did not consider all alternative explanations to account for the conclusions they based on their data. Although sometimes they made all possible crosses of cats, they did not analyze and interpret discrepant data within the context of their algorithm. This implied that participants memorized an algorithm without understanding or making connections between the algorithm and an experimental situation. These participants also experienced difficulty dealing with probability propositions and the probabilistic meaning of the Punnett square.

5.1.9.3 The Least Successful Participants

Those participants determined to be the least successful used random patterns of problem solving strategies. These participants, Lisa, Kate, and Mike, did not justify their actions during the inquiry project with valid scientific explanations. They typically cited circular explanations and justifications for selecting certain strategies, and they failed to investigate all possibilities. They would generate litters of kittens while switching inconsistently from investigating one trait to investigating another trait. They typically commented upon unexpected kitten phenotypes and pursued several traits at once, as they appeared in the litter.
5.1.9.4 Misconceptions

A number of misconceptions about basic genetics principles were revealed. The most prevalent misconception dealt with the Punnett square. Other misconceptions included:

- The phenotype that appeared the most as a result of the crosses between cats with different phenotypes was the dominant trait.
- A cross between two cats with different phenotypes producing cats with only one phenotype meant that phenotype was the dominant trait, and the parent must be homozygous dominant.
- If a trait is not common in the population it must be recessive.
- Dominant and recessive traits could be heterozygous.

Participants often failed to assess explanatory models based on how consistent they were with other accepted knowledge or ideas. In other instances, participants discarded models that could not explain data without attempting to discover the underlying conceptual problems with those models. In most cases, such problems involved inconsistency with meiotic processes such as segregation or assortment.

5.1.9.5 Progressing from Using Gut Feelings to Justifying Knowledge Claims

Some participants, especially biology majors, were initially very confident in their genetics knowledge. Additionally, they were not methodological in their investigations, at least in the beginning.

I didn't think it was going to be as complicated but then the further we got into it, the more complicated it got, so the more involved I got into it (Wilson interview, line 11).
Biology majors using their background knowledge made some erroneous knowledge claims based on assumptions rather than on experiments they conducted in Catlab. They also mentioned using their genetics common sense to make claims rather than data and evidence. One such incident was their claim that all-white coat color allele was recessive to non all-white coat color allele. When Lisa was asked how they came up with their conclusion she said:

We pretty much were just confident. We accepted it because I kind of knew already about white cats. We didn’t even test that. We were kind of using our genetic common sense (Lisa interview, line 219).

We just were like; well you don’t see that many white cats so it has to be recessive. So we didn’t even test it we just assumed (Lisa interview, line 222).

Wilson and Rachel also confirmed that at the beginning they were haphazardly mating random cats and recording data without thinking about any variable control or making predictions and testing hypothesis:

We were randomly crossing cats, and looking back it probably wasn't the smartest thing to do, but just getting lots of data, recording numbers, and getting values and stuff (Wilson interview, line 43).

We started by randomly crossing the cats and see what happens. It was very haphazard in the beginning (Rachel interview, line 6).

5.1.9.6 Recognizing Faulty Experiments and Alternative Hypotheses

Some of the participants showed expertise in testing a hypothesis after the module, while others failed to demonstrate the process skills of scientific inquiry associated with hypothesis testing. One of the interview questions was about an imaginary student who set up an experiment to test if the Manx trait was lethal in cats. After describing what the student did to test the hypothesis, interviewees were asked if they thought student’s procedures and conclusions were acceptable and asked to provide
an argument for their positions. Out of seven interviewees Ben, Kevin, Mary, and Wilson recognized what was wrong with the student’s set-up and assumptions right away, and they suggested multiple other ways to test the hypothesis while two participants, Karen and Lisa, could not identify the source of the problem. They also could not suggest a way to test the hypothesis. Rachel was able to work the problem out with some scaffolding.

Following is Kevin’s explanation:

I would say that her error is that when she set up this experiment she made the claim that the Manx trait is lethal meaning if you had homozygous Manx you would not survive so that means when she mated Manx cat with a tailed cat the program generated both Manx and tailed kittens that means she mated a heterozygous Manx with homozygous recessive tailed, and you get both. Than she takes two of the offspring’s one of them Manx and the other is Manx, so she gets one to one ratio. she rejected the hypothesis that Manx allele is lethal because she did not get 2 to 1 ratio she was expected but her expectation was wrong, she should get 1 to one ratio. She would get 2 to 1 ratio if they were both heterozygous Manx. One of the offspring would die and you would get 2 to 1 (Interview, line 117).

This is an excellent explanation; evidently Kevin had a very strong understanding of concepts that involved procedures to test a hypothesis. Similarly Ben and Mary were very quick to identify the problem and propose a correct way to test the hypothesis:

But then she selected two of these parents from F1 generation, a Manx male and a female tailed. What she should have done is to select two Manx cats, and if you’re assuming that it’s lethal, so you know you’re going to get a two to one. That’s totally bizarre, what she did. I’m confused why she would do that. Either she should have chosen two Manx parents in second cross or she should have expected one to one ratio instead of two to one ratio (Mary interview, line 155).

She selected these offspring’s she generated 89 Manx and tailed, well she crossed one of these with one of these, and that is just the original cross all over again. I don't know even why she expected it two to one ratio there what she should have done to cross two Manx cats and that would have
given her two to one ratio because that would have died and she would have two Manx and one normal (Ben interview, line 208).

Wilson emerged as group leader among the biology majors. He made the most of the mating decisions and analysis of outcomes. Lisa and Wilson were paired as a team. Wilson noted that Lisa exhibited a high level of frustration. Wilson described their group dynamic as follows:

Lisa would look at the problem and get frustrated and angry, and I would kind of sit there and offer solutions or ideas if something wasn't working. So we worked our way through it. We were kind of opposites, in the way we went about things, but, sometimes her ideas were just spur of the moment revelations and sometimes it panned out, and sometimes it didn't, and sometimes my calm clear-headedness panned out, if her ideas didn't (Interview, line 50).

Wilson demonstrated enhanced understandings, both in his genetics and inquiry. For the hypothesis testing question he offered a quick and definitive answer:

I think what she’s saying is that if there is a Manx it has to be heterozygous. Then Manx “M” is dominant and little “m” is recessive. But if you crossed them, you would get a 1:1 ratio. Same cross she did the first time, she should be expecting 1:1 ratios, her expectation was wrong. First, I would cross two tailed cats and expect 4:0 ratios. Then if I cross two Manx and I would end up with 2:1 ratio. She crossed the wrong cats (Interview, line 178).

Lisa, Karen, and Rachel, the least successful participants, had difficulties in articulating causal claims; they failed to cite sufficient data to support their arguments. In most cases they looked for plausibility as a sufficient criterion for justification and paid little attention to alternative hypotheses. The following quote refers to the bias towards confirmation that the majority of the participants had:

We felt comfortable with our genetics knowledge, so we didn’t really question too much. If we found, like, the Chi- square fit and it fit with our predictions we kind of just accepted it and we moved on, you know, we didn’t really double guess (Rachel interview, line 187).
The biology majors had confidence in their genetics knowledge in the beginning. This confidence in genetics influenced their approach to solving the inheritance problems. Instead of using the program to test knowledge claims, they tended to make assumptions and claim knowledge based on their prior constructions. However such behavior often backfired. When they discovered their faulty assumptions, and they found themselves to be incorrect, their level of frustration increased. This suggests a lack of understanding of the epistemic nature of scientific knowledge, and how data is used to support explanations.

Reflection is essential to learning in an inquiry context. Peer interaction and project presentations were very effective means of eliciting participant reflections on their data and findings. During these peer interactions they received critical feedback that could be used in subsequent inquiries. Successful participants challenged every knowledge proposition with no prior knowledge perspective; and they were more critical of their own and other’s claims. They demanded to see the data and evidence for every claim.

5.2 Second Theme: Participants’ Understandings and Learning about Mendelian Genetics Concepts

The second theme relates to the second research question: What are prospective secondary science teachers’ understandings of Mendelian genetics, and to what extent, if any, did participants develop more in-depth understandings about concepts of Mendelian genetics? Participants’ knowledge of genetics concepts were measured by pre- and post-questionnaires. Furthermore, their understandings of Mendelian concepts and abilities of
conducting scientific investigations to answer research questions were inferred from inquiry project reports, post interviews, and classroom discussions and observations.

I used paper and pencil pre-test and post-test measures to assess participant’s level of understanding of genetics concepts and principles. The pre-test included twelve items consisting of multiple choice and open-ended items on propositions of dominance, probability, gamete combinations, and the transmission of inheritance. The post-test included eighteen items. In order to determine changes in responses, the post-test included ten of the pre-test items, only in a different sequence.

Pre- and post-test items were constructed to measure propositions in three domains, namely gamete combination (GC), transmission of inheritance (I) and probability (P). Some items fell into more than one domain. Table 5-5 shows item numbers and their corresponding propositions.

<table>
<thead>
<tr>
<th>Item #</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5*</th>
<th>6*</th>
<th>7*</th>
<th>8*</th>
<th>9*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proposition</td>
<td>GC</td>
<td>GC</td>
<td>GC</td>
<td>GC</td>
<td>+</td>
<td>GC</td>
<td>GC</td>
<td>GC</td>
<td>GC</td>
</tr>
<tr>
<td>Item #</td>
<td>10</td>
<td>11</td>
<td>12</td>
<td>13</td>
<td>14*</td>
<td>15*</td>
<td>16*</td>
<td>17*</td>
<td>18*</td>
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<tr>
<td>Proposition</td>
<td>+</td>
<td>GC</td>
<td>GC</td>
<td>GC</td>
<td>GC</td>
<td>GC</td>
<td>GC</td>
<td>GC</td>
<td>GC</td>
</tr>
</tbody>
</table>

| GC: Gamete combination; P: Probability; I: Transmission of inheritance. *Item 5 and 18 were definitions of phenotype and the genotype respectively and item 10 was about forming a hypothesis. * These items were in both pre- and post-tests.

### 5.2.1 Analysis of Mendelian Genetics Pretest

The genetics pre-test revealed that initially most of the participants, even biology majors, did not have a deep conceptual understanding of Mendelian genetics. All
demonstrated a very mechanistic understanding of gamete combination and probability at the beginning. Item analysis of pre-tests showed that the major sources of difficulty for participants were items dealing with the determination of parental genotypes, which is directly related to the concept of probability. Number of correct responses (n=12) for each item is demonstrated in Figure 5-1.

![Number of Correct Responses by Item in Mendelian Genetics Pretest](image)

**Figure 5-1: Number of correct responses for each item in pre-test**

The lowest scoring items 3, 4, 5, and 6 were related and they had to do with determining parental genotypes after a specific cross. Only Kevin provided the correct response for item 3. Kevin and John both responded correctly to item 4. Kevin, Kate, and Rachel responded correctly to items 5 and 6. Interestingly, among these participants only Rachel majored in biology.

Although, participants who majored in biology scored higher on definition items on the pre-test, the first item related to defining genotype, was very problematic across all participants. For example Lisa, who majored in biology, provided the following definition for genotype: “The effect of different alleles” (Lisa, genetic pre-test).
Item 11 and item 12 were multiple choices questions and most of the participants answered these items correctly. Although they solved the problems and executed some procedural steps, some participants could not justify their algorithmic solutions using their conceptual knowledge.

The average percentage of correct responses in the pre-test was 39%. Figure 5-2 demonstrates percentage of correct responses by participants. Surprisingly, biology majors’ average percentage (38%) was not higher than the average percentage for participants majoring in other disciplines (40%). In spite of their extensive coursework in biological sciences, the biology majors did not possess adequate conceptual understandings of Mendelian genetics.

![Figure 5-2: Participants’ percentage of correct responses in genetics pre-test](image-url)
5.2.2 Analysis of Mendelian Genetics Post-tests

After the module, prospective science teachers demonstrated enhanced understandings of Mendelian genetics concepts. Post-test results showed considerable improvement given the short time span and the focus of the module.

The number of correct responses for each item in the post-test is demonstrated in Figure 5-3. Ten items were the same in pre- and post-tests. Items 6, 7, 8, and 9 in the post-test corresponded to items 3, 4, 5, and 6 in the pre-test. Similarly, items 14, 15, 16, and 17 in post-test corresponded to items 7, 8, 9, and 10 in the pre-test. Finally, item 18 in the post-test were the same as item 1 in the pre-test, and item 5 in the posttest was the same as item 2 in the pre-test.

Figure 5-3: Number of correct responses for each item in post-test
Prospective teachers still appeared to struggle the most with the concept of probability. The items with the lowest correct responses dealt with determining genotypes of individuals and probability. Similar to the pre-test, only one participant answered item 6 correctly in post-test. Instead of Kevin, Mary was able to provide the right answer in the post-test. While Mary showed very significant improvement by answering all questions correctly, Kevin failed to recognize the probabilistic nature of the situation in post-test. Related to probability participants used the Punnett square without conceptual understanding. Although almost all knew how to construct and use the Punnet square; the conceptual knowledge and cognitive operations behind the Punnet square were mostly absent. When presented with the same problem stated in a different way, participants failed to answer correctly. Another problem was the learning of the basic terminology of Mendelian genetics. They frequently used allele and gene concepts interchangeably.

The percentage of correct responses in the post-test for each participant is reported in Figure 5-4. The average percentage of correct responses in the post-test improved to 67%.
The majority of participants responded correctly on definition items, but had more difficulty with items requiring application and analysis of genetics concepts. This was true even when information was supplied in the text of the problem. For example, item 12 in the post-test illustrates this point. Half of the participants explained their choice as follows: since the first cross between orange and white birds produced half of each color in the offspring, crossing one of the orange offspring with an unrelated white bird will result in 2 orange and 2 white chicks. Punnett square indicates half of each color. However this line of thinking would not result in the right choice, since a cross between a heterozygous dominant parent and recessive parent will result in a 50/50 chance of one chick being orange or white.

**Figure 5-4: Participants’ percentage of correct responses in genetics post-test**
5.2.3 Comparison of Mendelian Genetics Pre- and Post-Tests

As stated earlier, participants demonstrated significant improvement in their understandings of some of Mendelian genetics concepts. Average percentage of correct response was improved from 39% in the pre-test to 67% in the post-test. Figure 5-5 demonstrates summary and comparison of pre and post genetics tests based on ten same items.

Figure 5-5: Percentage of correct responses in genetics pre- and post-tests

Since only ten items were the same in the pre- and post-tests and items dealing with probability and determination of parental gametes were problematic among all participants even after the module, Figure 5-5 does not show the complete picture. Still, we can see that the most dramatic improvement was among non-biology majors. Among biology majors only, Wilson showed a radical improvement. In order to see the improvement in Mendelian genetics understandings of prospective teachers, we need to
look at their performance on the post-test items. Figure 5-6 displays the number of correct and incorrect responses in Mendelian genetics post-test.

Figure 5-6: Number of correct and incorrect responses in the post-test

When confronted with unexpected data to analyze and interpret, nearly all participants did not consider all possible explanations. One common misconception involved the meaning of the Punnett square. Several participants explained the appearance of three black kittens and one grey kitten from a cross of a two black cats as consistent with the Punnett square predictions for crossing two heterozygous parents. They stated that the Punnett square showed that three kittens would be black and one kitten would be grey. However, in fact, the square represented the probability for one kitten’s appearance and not the probabilities of four kitten’s appearance. Therefore, these particular participants did not fully understand and correctly interpret the nature of probability and the representation of Punnett square during their inquiry projects.
Although Mary had a limited biology background, she scored higher than others in the post-test. This point will be discussed later on in this chapter.

**5.2.4 Learning about Mendelian Genetics**

All pairs came up with well substantiated answers to their driving inquiry questions. In fact, in final presentations they were able to identify a total of seven genes and the interaction with one another; (participants did not know how many sets of genes Catlab included). Basically they completely figured out the inheritance model upon which the Catlab program was built. In final interviews, when they were asked if they learned Mendelian genetics as a result of their experiences in this module, they self-reported:

I definitely learned about genetics. I learned through experimentation and trying different things and seeing what happens in the Catlab program. We would do crosses and something would happen and we would have to come up with explanations for it (Ben interview, line 14).

I believe that I learned genetics in this process. I had very little genetics knowledge. I knew what a gene is, and I knew traits pass through genes, stuff like that. By the time I ended, I think, I know a lot more, like processes how to find out which gene is dominant, how to determine sex-linked, autosomal, co-dominance, and all these things were in the problems that were presented (Kevin interview, line 9).

Table 5-6 displays the list of the Mendelian genetics concepts verbalized by the participants during the interviews.
Table 5-6: Mendelian Inheritance Concepts Verbalized by the Participants

<table>
<thead>
<tr>
<th>Offspring</th>
<th>Percent</th>
<th>3:1 ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parent</td>
<td>Ratios</td>
<td>Odds</td>
</tr>
<tr>
<td>Cross</td>
<td>Specific cross</td>
<td>Backcross</td>
</tr>
<tr>
<td>Independent</td>
<td>50/50 chance</td>
<td>Hybrid</td>
</tr>
<tr>
<td>assortment</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dominant</td>
<td>Specific genotype</td>
<td>F1</td>
</tr>
<tr>
<td>Recessive</td>
<td>Heterozygous</td>
<td>Random</td>
</tr>
<tr>
<td></td>
<td>dominant</td>
<td></td>
</tr>
<tr>
<td>Trait</td>
<td>Homozygous recessive</td>
<td>Pure</td>
</tr>
<tr>
<td>Sex linked</td>
<td>Chance</td>
<td>Sample size</td>
</tr>
<tr>
<td>Homozygous</td>
<td>1 in 16</td>
<td>Mutation</td>
</tr>
<tr>
<td>Heterozygous</td>
<td>Recessive trait</td>
<td>Specific ratios</td>
</tr>
<tr>
<td>Punnet square</td>
<td>Dominant gene</td>
<td>Chi square test</td>
</tr>
<tr>
<td>Probability</td>
<td>Statistically significant</td>
<td></td>
</tr>
</tbody>
</table>

Mary had her undergraduate degree in physics and mathematics and never had a biology class. At the beginning of the module, Mary was very frustrated. Yet, Mary demonstrated the most significant progress by correctly answering all the questions in post-test. She exhibited successful strategies during the inquiry project investigations. Mary’s background included a significant experience in research: “I spent two summers in Oak Ridge and a year in grad school, just taking data, writing it down” (Mary interview, line 17). In her interview she recognized her enhanced learning:
I definitely learned about Mendelian inheritance. Explaining why I have blue eyes and my parents don’t . . . yeah, I can explain my cat, it was very exciting. I can write out some of the genotypes on my cat, I know what she is (Mary Interview, line19).

Although she was biology major, Karen reported that she never had a full semester course in genetics. Instead she was introduced to Mendelian concepts in her other biology courses:

I definitely learned genetics in the Catlab (Karen Interview, line11).

Similarly Lisa, secondary education biology major, said:

I guess my genetics knowledge increased, like especially cat genetics (Lisa Interview, line 32)

Wilson and Rachel were both biology majors, and they thought this module helped them recall their previous knowledge of genetics. They said:

It kind of refreshed my memory, and brushed up on incomplete dominance and complete dominance and things like that so it was kind of what a memory refresher (Wilson Interview, line 14).

Everything we did was refreshing my memory for me. Definitely I learn a lot about cats’ genetics. I was home and looking at my cat and saying I know why you are the way you are (Rachel Interview, line 8).

However, when they were asked if they thought other participants learned Mendelian genetics they stated:

Yes, I think the people who weren't used to genetics, like the physics and chemistry majors learned a lot. Because when we gave the introduction to homozygous, heterozygous, and Punnett squares you could tell they were a bit hesitant about all the knowledge. I think they learned a lot, at least about simple genetics like dominant and recessive and the ideas of co-dominance and genes affecting other genes and controlling genes (Wilson Interview, line 84).

Yes. In the beginning I remember some people being very frustrated because they just never had genetics. At the end they were very excited to present what they found because they did finally understand it. People
who feel need to understand made better progress than others (Rachel Interview, line 69).

Prospective science teachers learned about Mendelian genetics concepts during their investigations. They acquired knowledge about experimentation and hypothesis testing. The most problematic issues had to do with concepts of probability. One of the reasons for Mary’s success in this module was her understanding of probability:

I knew how to do it once I had the terminology, because it’s really just probability theory (Mary interview, line 27).

These kinds of experiences are very rare not only in science teacher education programs, but also in science departments, as evident in Rachel’s statement:

None of us really used to do anything like that. Until now it has always been very structured research experience; that is another reason that this experience was valuable (Rachel Interview, line 17).

5.2.5 Analysis of Inquiry Project Reports

Several of the participants displayed a degree of impulsivity, starting to test their ideas immediately, while others were concerned about identifying the variables and thinking about how the tests should be conducted before beginning to test. Analysis of final inquiry project reports revealed that participants developed skills in the following areas: 1) assigning genotypes; 2) understanding of genetics ratios, using this knowledge in predicting possible outcomes of mating specific cats; 3) features of inheritance of monogenic traits, such as dominant, recessive, incomplete, Autosomal, and sex-linked; 4) formulating inheritance models and testing them; 5) logic of hypothesis testing and falsification method; 6) inferring genetic phenomena such as linkage, gene interaction, and lethality.
5.2.5.1 Inquiry Project Questions and Pairs

Biology majors, unknowingly, selected the most open-ended question. Two pairs of biology majors, Wilson / Lisa and Rachel / Karen, selected the following questions for their inquiry project: “Investigate and determine the inheritance pattern of the orange tabby striping trait in cats. Generate as much as data as you feel is necessary to support your conclusions about the inheritance pattern. Record your data and present it in your final presentations.”

The inheritance of orange trait in cats is controlled by an X-linked gene. Initially the biology majors thought this question was the easiest one, however later on they realized that in order to answer their question they had to have a complete model of inheritance of coat color in cats. After the second session the two pairs of biology majors merged together and started to work collaboratively on the problem.

They identified and presented following six genes and alleles for each gene effecting coat color and patterns in cats: 1) black and orange alleles are sex linked (carried on X chromosome) and co-dominant; 2) undiluted allele is dominant to the diluted allele; 3) all-white allele is dominant to not all-white allele; 4) white spotting and no white spotting alleles are an example for incomplete dominance; 5) tabby allele is dominant to the non-tabby allele; 6) mackerel tabby pattern is dominant to the blotched tabby pattern.

Kevin and Ben were paired together and their driving question was: “A student set up the cross: Gray blotched tabby female x Cream blotched tabby male and obtained a large number of kittens. The student observed that no cream blotched female kittens appeared among the offspring and concluded the only explanation was that these females
died in uterus. Is the student correct? Use Catlab to explore this situation and attempt to formulate a genetic model to explain the result observed by the student.”

Kevin and Ben correctly, concluded that a genetic model consistent with observation is that there is a sex-linked gene with two alleles; gray and cream. They compiled their results into a list of four genes as follows: The first gene is the “presence of orange” gene, which is located on the X chromosome, making it sex-linked. This gene is also co-dominant, so if the cat is heterozygous for the gene, it will be either black & orange or gray & cream. The second gene is an autosomal gene that determined whether the color or colors expressed were dark or light, and dark was the dominant allele. The third gene is an autosomal gene for whether or not a cat’s tabby pattern is blotched or mackerel, and mackerel is the dominant allele. The last gene discussed was an Autosomal one which codes for whether or not a cat expresses its tabby pattern, and expression is dominant to non-expression. That tabby gene would be overridden if a cat would be homo- or hemizygous for an orange shade, making it automatically tabby.

Mary and John’s guiding question was: “A cat breeder claimed that the mating of two tabby cats could occasionally produce a non-tabby kitten, but that the mating of two non-tabby cats apparently never produced a tabby kitten. Do you agree with the breeder’s observation? Can you suggest an explanation for your observations?” In this question there are two genes that are involved. An example of gene interaction in which alleles of one gene cover-up or alter phenotypic expression of alleles at another locus. In epistasis, modified phenotypic expression may result from a particular combination of alleles present at different genes. In this case the presence of non-tabby allele masks the action
of the tabby pattern gene. Ashley and Mike also worked on this question. Similar to biology majors these two pairs also shared a lot of data and worked together.

Mary and John reported that they predicted that there were two genes at work, one for solid versus tabby and one for blotched versus mackerel striping patterns. They summarized their conclusions as follows: “We knew from a previous experiment that the mackerel-stripping pattern is dominant to the blotched pattern, and we predicted that the tabby pattern is dominant to solid. If a cat is homozygous solid, the cat will not display its striping pattern no matter which striped gene it has. For the colored cats, we agree with the cat breeder’s observations with two tabby cats can produce a solid kitten; however, in the course of our investigations, we have found that two solid cats can produce tabby kittens.” Ashley and Mike reported similar results. After answering their guiding question these four participants also explored and reported the following genes: 1) White vs. non-white gene: All white is dominant to not all white; 2) Extensive white spotting vs. some white spotting vs. no white spotting: two alleles are incomplete dominant over each other; 3) Manx vs. tailed: Manx (not having a tail) is dominant to having a tail.

Valerie and Kate worked on the following guiding question: “Some conditions are lethal in the homozygous state, for example yellow coat color in mice. Does this also apply to all-white coat color in cats? Use Catlab to explore the inheritance of all-white coat color. Propose a genetic explanation consistent with the results you obtain.”

After conducting a series of investigations, Valerie and Kate determined that all-white gene was not lethal in cats. They reported that all-white allele was dominant to the not-all white allele. They also investigated the Manx trait and reported that the Manx allele was dominant to the not-Manx allele.
Analysis of the inquiry project reports revealed a list of problem solving behaviors that participants employed during the inquiry projects. Table 5-7 provides the descriptions of problem solving behaviors.
Table 5-7: Descriptions of Problem Solving Behaviors during Inquiry Projects

- Formulating question of problem statement
- Starting over
- Generating hypothesis or alternative hypothesis
- Retaining hypothesis
- Adding a cat
- Recalling the list of cats
- Selecting cats to cross
- Repeating the cross
- Predicting results based on previous knowledge
- Stating action to be done
- Executing action previously stated
- Generating data
- Stating a rationale for the action
- Giving the qualitative description of observations
- Giving the quantitative description of observations
- Recording data
- Translating or transform data into other forms
- Determining qualitative relationship
- Drawing final conclusion
- Stating that results are inconclusive
- Determining quantitative relationship
The total of seven genes was identified by the six pairs. In summary, the participants collaboratively were able to identify all genes and their alleles and their interactions in the Catlab model.

Genetics has been acknowledged as one of the most difficult topics for high school and undergraduate students (Lawson, 1992; Mitchell & Lawson, 1988). Many genetics concepts are based on theoretical entities constructed within abstract hypothetico-deductive conceptual systems. Therefore, successful acquisition of genetics concepts requires learners to reason hypothetico-deductively. Yet, research indicates that substantial percentages of college undergraduates have failed to acquire such reasoning skills (Lawson, 2002). In order to assure meaningful concept acquisition and enhance abilities to do inquiry, instruction should be designed to improve learners’ scientific reasoning abilities. Learners’ scientific reasoning ability has been found to influence their achievement in conducting investigations and learning genetics (Lawson & Weser, 1990; Mitchell & Lawson, 1988).
5.3 Third Theme: Participants’ Perspectives of the Learning Environment and of Inquiry-Based Teaching

The third theme related to the third research question: From the learners’ perspective, what were the instructional strategies and classroom interactions in this module that contributed to their understandings of scientific inquiry and Mendelian genetics, as well as to development of abilities to do scientific inquiry? Participants gave positive feedback about the learning environment citing the value of their peer interactions, project investigations, and their classroom presentations. Interview analysis revealed that participants reported the following experiences as important during Catlab module: 1) developing critical thinking, 2) developing inquiry skills, 3) ill-structured nature of the process, 4) initial frustration in the process, 5) losing self-confidence, 6) revising experimental design, 7) valuing learning from peers, and 8) satisfaction of discovery.

Participants were positive about the classroom atmosphere and often talked about how it was very helpful to collaborate with peers. The value of peer interaction and collaboration were cited by all interviewees. For example, Rachel said:

If people were not friendly and communicating I don't think a lot of people would have gotten the answers at all.

In his interview Wilson stated:

First of all it was fun, just being able to figure it out, instead of somebody just telling me what the genetics were, and there's a sense of pride that you accomplished something. I liked how it promotes critical thinking. Students today usually are fed cookbook labs, and using guided inquiry will help increase their critical thinking (post interview, line 217).

Experiencing inquiry in such a classroom environment also helped participants to reflect about aspects of nature of science, Kevin said:
Having to look at other people’s data and discussing it, the social aspect of it was great also science is subject to change, and we got a really good glimpse of seeing that, because every time we came up with a hypothesis that we thought was good, it later proved wrong. I think it's important to understand that aspect of science. You can sometimes learn more from having a hypothesis that's wrong than having one that the data supported.

5.3.1 Attitudes towards Inquiry-Based Learning

Participants expressed both positive and negative feelings about inquiry during the interviews; attitudes towards inquiry were mostly associated with past learning experiences, general personality, and lack of inquiry experiences. Ben and Kevin, majored in Earth and Space science, as a pair were very successful with the Catlab project and they enjoyed the experience. They both had a curious and a competitive nature, and according to them “they want to know stuff.” After answering their project question they wanted to explain more and were testing different hypotheses, in the interview Ben replied:

I don't think we ever felt like we were done, until we were sitting after final presentations with the list of genes we came up with on the board and you said congratulations you found all the genes, that was the only point we finally felt, because Kevin and I if we had another day we would have moved on to the Manx and the albino traits, those were the two we never got around to investigate if we had another day I am sure we would solve those too (Interview, line 181).

Similarly Kevin stated:

I think, we learned a lot even if we wouldn't have come to the final answers if we run out of time or just gotten it wrong we still would have learned a lot because with inquiry we become more interested in it and we spent more time thinking about it and wanted to learn, I learned a lot from this experience about doing inquiry, it is an important key in my understanding on how inquiry works, and I feel more prepared in doing inquiry (Interview, line 279).
Some participants had negative feelings toward inquiry, and stated they prefer a more structured, teacher-centered learning environment. In her interview Lisa said:

There were some parts that I felt overwhelmed, like out in left field. I was not sure if we were on the right track and that is frustrating to me. I like to know if I'm doing something wrong (Interview, line 192).

Although she believed inquiry-based learning was beneficial, Karen wanted to add that:

I like to have answers immediately. Having to figure out how to get to the answer sometimes drives me nuts. That’s just a personal trait there. I think that’s why I got frustrated a lot with inquiry. I think it’s a lot more not knowing, just “see as you go,” that process, so sometimes I would get really frustrated with it (Interview, line 105).

Similarly, after successfully completing her inquiry project and having sound understanding of Mendelian genetics, Mary wanted to receive direct instruction about inquiry-based learning. She said:

Honestly. I want someone to sit down with me and lecture me about it; like do non-inquiry things about inquiry, just so I can sit down and go, “Oh, that’s what I’m supposed to be doing” (Interview, line 147).

Rachel valued the experience and admitted to being frustrated with the inquiry. As a student engaging in inquiry, it was a new experience and frustrating one. At the same time it was a lot of fun. Frustration helps you understand hundreds times better since you have to work through all these processes.

Lisa referred to critical thinking:

I did like how it promotes critical thinking. Students today usually are fed cookbook labs, and using guided inquiry will help increase their critical thinking.
5.3.1.1 Perspectives about Using Learning Technology

Catlab has a great potential to help science teachers to implement inquiry-based teaching into their classrooms. Prospective science teachers’ views about Catlab were highly positive, for example, Ben stated:

It was very fun, we really got into it, and we learned a lot. Also I think it was very enjoyable scientific modeling program, it really did worked well, easy to use, and informative I liked the program (Interview, line 174).

They enjoyed the program as it related to their lives since many of them have cats at home: the following excerpt from Mary’s interview illustrates this point: “I can explain my cat, it was very exciting.” Kevin majored in Earth and Space science and had little biology background; he enjoyed working with Catlab. In his interview he said:

No matter who you are and what background knowledge you have you can understand and learn what is going on in this program (Interview, line 228).

Rachel was a prospective biology teacher; she thought Catlab could be very useful in teaching genetics to high school students, in her interview about Catlab she said:

It is a good way to convey some of the concepts in genetics, and it really illustrates every gene interaction. It also teaches you how to ask a scientific problem and explore it (Interview, line 223).

Another prospective biology teacher, Karen, had mixed emotions about Catlab and inquiry based learning. She said:

It definitely made me not like inquiry a lot, just throughout it, just because it was very frustrating at times, but, looking back, it was definitely great, like . . ., but I think I got a lot out of it, even from like basic genetics stuff, ‘cause I could mate two cats and say “Oh, this happens immediately.” There was instantaneous reward or reinforcement (Interview, line 37).

Wilson thought he learned from this experience and saw how one can learn from inquiry:
I would be better in inquiry, I saw a structure of how to do it, opening with a driving question and seeing how the vagueness eventually led to clues which eventually led to the process which after going through you understand what you have to be incorporating into each step of your inquiry (Interview, line 110).

During the final interviews, participants discussed their views on the module. The useful aspects that participants discussed included the ease of using the simulation and the simplicity of interface, working in pairs, and improved inheritance conceptions. Their views about what they found confusing about the module included time constraints, need for answers, too many variables, and ill-structured nature of the activity, and prior knowledge of the content and the simulation.

Participants’ views on the module help to support an important claim of this study and to confirm findings from other simulation-based research. First, an implicit assumption of this research was that the simulation would be a useful cognitive tool in helping users to learn about and to improve their understanding of Mendelian genetics concepts. All interviewees self-reported that the simulation helped them to improve their conceptual understanding of some aspect of Mendelian genetics. Second, those features of the module that participants found confusing (e.g., not enough time, dealing with too many variables, lack of prior knowledge both in content and in using the simulation) are consistent with research that examined the effective use and design of simulations as a learning tool (de Jong & van Joolingen, 1998; Windschitl, 1998). These results suggest that simulations can indeed be implemented into curriculum as useful learning tools.
5.3.1.2 Succeeding in Inquiry Learning

Deriving from their own experiences participants mentioned several characteristics for a learner to be successful in inquiry learning environment. These characteristics were a) being patient; b) being open minded; c) drive to learn and being competitive; d) recognizing patterns; e) being creative; f) problem solving and critical thinking ability g) peer review. The following excerpts from interviews display participants’ responses:

I think patience is good while doing inquiry, trying to avoid bias and having a broad range of thought, peer interaction, and peer review is important and the drive to figure it out, or working on something you are passionate about (Wilson interview, line 96).

Besides the drive and passion to figure something out I think it is helpful if you are sort of used to recognizing patterns. To do inquiry well you need to practice (Rachel interview, line 57).

I think you need patience and if you’re creative inquiry works better for you (Karen interview, line 121).

Our attitudes were kind of competitive; we wanted to know what would work. We kept going. There were few groups who would hit a block and give up, get discouraged. We would try even harder. It also has to do a lot with problem solving ability (Kevin interview, line 75).

5.3.2 Important Role of Preliminary Presentations

In the middle of the module I interjected a time for preliminary project presentations. Participants had a chance to see what other pairs had done, up to that point. Pairs reported on what kind of data they collected and on explanations they constructed, as well as strategies they used and their preliminary conclusions. They had an opportunity to compare and contrast their data, findings, and conclusions with their peers and evaluate their developing project. This activity proved to be very valuable as it provoked heated discussions and debates between pairs. Some of the participants saw more
evidence that supported their claims and models, while others saw alternative as well as contradictory explanations and models.

For example when asked about when he started testing hypotheses, instead of just randomly mating cats, Wilson said:

I’d say, right after the mid-way point, when we started discussing in class, and we saw everybody else's views. We had hypotheses, and we were getting data that was rejecting them. Because, every test we did was rejecting what we were thinking. So, when we came together, we finally saw some other groups’ ideas, and we systematically started to prove one point after another (Interview, line 44).

Ben and Kevin also valued the preliminary presentations and their role:

Presentations gave us different ways of looking at things; we'd say maybe that can apply to our model (Ben interview, line 58).

We enjoyed arguing because it made us think about more of our ideas (Kevin interview, line 53).

Similarly, Karen expressed a positive opinion about the preliminary presentations stating:

It was really good how we met a couple times go over, we didn’t agree with everything from the other groups, but then, we found out by going back and testing out their hypotheses, it actually helped us, so if another group found something, and we didn’t really understand what was going on, we could go ask them and they would show us their process and we could compare results. So that was really good.

Preliminary presentations also influenced prospective science teachers’ understandings of science and nature of science. Their understandings became more process-oriented rather than product driven. In their explanations, they put more emphasis on data and evidence and the multiple inquiry procedure that scientists might use in their research. Most of the participants stressed social aspects of science and scientific communities that share similar interest and work together.
The way you go about science, the processes, I have learned a lot just from that. The scientific experience and the community were probably the biggest help for my understanding. Asking other people what they have done, showing them your data and seeing if they had any explanations for that and being willing to throw out your explanations the moment data didn't fit it and come up with something new (Ben interview, line 161).

In addition to creating ideas, the participants’ social interaction facilitated to generate problems and clarifications.

### 5.3.2.1 Debate and Discussion Leads to Consensus and Understanding

Although they did not have compelling evidence, in their preliminary presentation, Ben and Kevin introduced the most radical and thought shifting idea: what they called the Dark & Light gene. According to their inheritance model, if a cat has a dark allele it would be Orange or Black. If it has a light allele, then it would be Cream or Gray. This gene was independent from any other color gene.

As soon as Ben and Kevin introduced the idea, all the biology majors were harshly critical and they did not even consider the possibility of such a gene. There was a very heated discussion. In fact, right after presentations, biology majors, especially Lisa, stopped their investigations and they tried to disprove Ben and Kevin’s dark & light gene idea. Such competition reflected real scientific endeavor for participants. During his interview Kevin said:

I thought that was neat, because they did not necessarily accept it but it was something that came up with an explanation that people had not thought of so right away, I mean, it was just kind of the real science, you know, someone comes up with a new theory and people do not want their theory to be wrong so they try to prove it wrong (Interview, line 46).

It was funny, because when we did the preliminary presentation, Ben and I, we were talking we did not want to share what we had because we had not fully explained everything so we wanted to be the first ones to do it.
We really did not want to give hints to people so that they might jump at it, in a way I really felt like a scientist (Interview, line 49).

Ben also commented on competition between groups:

We had a little bit too much fun and got really competitive because we were both earth science majors and we weren't to beat the biology majors. They seem to so sure that they were going to get all the answers and we were doing well, that was matter of pride (interview, line 65)

After conducting numerous experiments, the biology majors failed to disprove dark & light gene. In fact they realized that it was very useful idea and could help them to explain their data as well. However, they did not accept it as dark & light gene. The following interview quotes are from biology majors. Karen described the process:

We hadn't really ever thought about dark & light gene until they brought it up, and we didn't agree with it. We were so against it that we went into Catlab and we started testing it (Interview, line 76).

Secondary education biology majors renamed the dark & light as dilute & undiluted and claimed that their language was more scientific. Rachel said:

Lisa and Wilson modified it like dilute & un-dilute. Until that point we were thinking all the genes were separate and not affecting each other. Changing the language helped Lisa and Wilson to make it more scientific (Interview, line 87)

Lisa said that prior knowledge of genetics actually prevented them from being as open-minded as others in class, and they assumed too much, instead of using actual data and evidence. She also had a problem with the language that Ben and Kevin used:

Everybody was so passionate and they think their way is the right way. We thought we were definitely on track and knew what was going on and so we pretty much tried to disprove what other people were saying. I think our prior knowledge was hindering us for that task. I was like light . . . Dark . . . see the thing is their wording; light and dark, I didn't like. So I said that is not right, but if they would have said dilute and un-dilute right away I think it would have clicked, because that is how we described it in my other classes (Interview, line 255).
Wilson gave credit to Ben & Kevin for their idea, however he too emphasized that their language was not scientific:

When Kevin started talking about dark versus light I thought it was an interesting idea, I didn't see so much as dark and light I was a little more scientific about dilute and un-dilute and how colors are changing and thought there might be a gene affecting the amount of color and that's what's changing it. As soon as that idea came about, it explained so much and so much became clearer, because it explained so many aspects. It was the idea that was needed (Interview, line 119).

I was curious about how Ben and Kevin discovered dark/light gene. In their interviews both of them explained the same procedure. They recognized that although they were able to add an orange and black or cream and gray cat into the litter, Catlab simulation did not have options for adding orange and gray or cream and black cat. In short, dark colors did not go together with light colors. In order to test their prediction, they tried to breed an offspring kitten that had orange and gray or black and cream coat color. The Catlab program did not generate such a kitten. They read the clues that were inherent within the simulation to solve the problem. In interviews I asked if they used the features of the program in the process of building their inheritance model:

When selecting the phenotypes you can see that with the certain tabby cats you could or could not create certain cats and you won't get certain color combinations. We tried to ignore it as much as we could but it's being there we knew, okay, it says there you cannot select a cream and black female (Ben interview, line 119).

On the other hand Lisa was upset because she could not add non-tabby cream cat into the litter. She insisted that her friend has a non-tabby cream cat and she saw a couple of others so Catlab was limited. In fact, genetically, all orange and all cream cats are tabby cats; solid cream cats look like non-tabby because we cannot see the mackerel stripes or blotch pattern. After building their inheritance models participants recognized
that information they entered into the simulation corresponded to genes they were trying
to discover. In their comments, they noted surprise and resentment for not being able to
recognize such an obvious procedure:

> After figuring everything out, I looked at the program, and realized the
> program tells you what it is, each gene was set up in another set of
> separate boxes, and I was thinking how stupid are we? We just never took
> the time and considered looking at it (Wilson interview, line 128).

We did not realize until the end, when we finally realize that these are the
all the genes we are going to present, we were looking at each other and
wondering how stupid we all have been. All this time we were wondering
why we were not able to select some cats we wanted and thought program
was limited because it does not offer these mixes. We did not think
genetics based reasons of it (Rachel interview, line 81).

Each box we checked was an allele; we find that out at the end. Wilson
said “do you know how stupid we are?” We had done everything and then
Wilson saw it all, and we all just felt too stupid at that point. It took going
through all of it and getting everything done before we could go back and
say “Oh my god, it was staring us in the face the whole time” (Karen
interview, line 139).

In final presentations pairs who majored in biology used dilute/un-dilute whereas
Ben and Kevin referred to the same gene as dark/light gene. Participants tended to be
more critical about their explanations and models when different ideas were presented to
them by their peers. On the other hand they tended to ignore discrepant data in favor of
their explanations.

5.3.3 Participants’ Perspectives of the Instructor during the Module

The instructor’s role in inquiry based instruction is integral to the appropriate use
of technology and instructional activities. All participants reported that teacher guidance
is necessary for the effective use of the simulation. Guidance strategies included pointing
out discrepant information and/or data and directing participants’ attentions on particular
trait, cross, or litter; asking questions such as “What is wrong with this?” or “Why?” suggesting strategies such as, “Work back from the data,” making comparisons, and encouraging participants to control variables and generate more data. Several of the participants displayed a degree of impulsivity, in which they started to test immediately, while others were concerned about identifying the variables and thought about how the tests should be conducted before beginning to test.

When participants were asked about the instructor’s role during this module they gave the following responses:

Karen said:

I would say you were more like a facilitator. When we were asking you some questions, you never really told us answers, you were like “go try this” and we were like “No, I want to know what exactly is going on.” . . . As a teacher you were there, but you weren’t holding our hands, you were just guiding us when we got stuck, it definitely helped me to see how as a teacher to use inquiry in the classroom, set up a rough outline and let them go off and do it, and when they have questions you try to help them but you don’t want to do baby steps where you tell them every little step.

Kevin stated:

I would say your role was less of a teacher and more of a like a mentor. Almost like another peer in the room it seemed. Our learning came from our experiences with the simulation with our peers and our interactions with you as a teacher came in to play when no one else could really help or if there was a situation where we were going in the direction that was really wrong and even then you would never come up and say, “No don't do this, go here.” You would say, “Well keep doing what you are doing but how do you explain this?” You would just put that question maybe in an observation that we were missing. You would be like, “Well look at this observation here now go with that.” I think that was neat.

Ben stated:

You were acting more as a facilitator: You made sure everyone was okay in what they were doing, like they weren't just reaching to dead end and
being stuck there. I think you were kind of pushing us along giving us more stuff to think about.

Rachel said:

You sort of let us loose, and then every once in a while come and focus us saying, “What about this?” And then we would say, “Hmm, let's figure it out.” We had to do our own investigation using the program to come up with the answers to every question we had in mind.

Wilson said:

As we were doing the project you would come along and see our answers and say, “What do you think about this?” or “What happens when you do this?” not to openly point us in the right direction, but to make us think about the way we could go to figure out the answer.

Lisa:

You did a good job when you came and said things like, “Cross these two and see what happens,” And then we would cross it and we would be like, “Oh . . . we need to go back and like check this out.”

Having a context for an inquiry was very helpful for being able to guide and provide support and scaffolds to participants. In context-free inquiry environment such roles for instructor would not be possible or feasible. Participants all were engaged in more or less similar type of investigation in the context of Mendelian genetics. They did not only benefit from instructors roles as guide, collaborator, and fellow researcher but also from their peers and interactions of the classroom. Instructors’ roles in this module also served as an example for prospective teachers in their future practice.

5.3.4 Intentions to Use Inquiry Teaching in the Future

Participants had mixed views when asked about their willingness to enact inquiry in their teaching in the future. All of them stated some kind of general willingness to do
so, yet, they also mentioned some reservations and practical considerations about inquiry-based teaching.

For example Karen stated that she would use Catlab, but she might attempt small scale inquiries:

I would totally want to use this in the classroom, but toned down to my grade level . . . I definitely couldn’t have 20 kids doing some kind of inquiry stuff, because they’re going to have questions and I won’t tell them everything, but I want to help each kid out and guide them through their process. These are pretty hard to do, not like these huge projects, but do inquiry in little experiments along the way and stuff (Interview, line 133)

Kevin could envision using inquiry in his classroom:

I would do inquiry in my class. I will have students doing inquiry with little or no problem and I will have students who will just give up. It was interesting feeling it and witnessing it, because it is something that I want to use (post interview, line 211).

Wilson also expressed positive feelings about using inquiry:

And so the overall process, and the way it went about would be useful as a teaching tool (Interview, line 74).

He elaborated on his intentions:

As a future teacher, I think it was helpful in showing ways of inquiry; giving the driving question, having a program or activity for the students to work at and being able to know, meet, and see what everyone is finding out part way through, discussing ideas, through peer. And seeing people's opposing ideas and thinking, "No, they're wrong," But then when you think about it you can use logic to rationalize your way through it to find the right answer which was helpful (Interview, line 66).

Wilson talked about the value of inquiry and how it is a fruitful experience as a teacher;

Inquiry is a method you would use to stimulate the thinking among your students, so inquiry promotes understanding among the students instead of just learning facts. There’s more of an understanding of the processes involved (Interview, line 48).
When asked about implementing the Catlab program into her teaching Lisa had positive feelings:

I really liked it and I actually would use it in a classroom setting eventually (Interview, line 135).

However, Lisa was cautious in her complete endorsement of using inquiry in her own teaching.

I just have mixed feelings about scientific inquiry. I definitely think that there is a place for it, but I wouldn’t try to incorporate it into every lesson, because I think you lose too many people, you'll frustrate people that aren’t really zealous or eager to learn (Interview, line 123).

Many prospective teachers are constrained by their own learning experiences in that their models of teaching and learning are often shaped while they are students. Lisa’s views of using inquiry apparently stemmed from her own experiences in high school science and while she favored guided inquiry, she stated some concerns about open-ended inquiry:

I do not think I will use open-ended inquiry in my classroom. I feel it creates a feeling of resentment toward science. When I was in high school, I was not taught using inquiry, and I do not feel like I was deprived. I am not saying I want to exclude it totally from my classroom, I just personally do not think open-ended inquiry is feasible in a high school setting (Interview, line 109).

Rachel valued the experience and admitted to be frustrated with the inquiry. As a student engaging in inquiry, it was a new experience and frustrating one. At the same time it was a lot of fun. Frustration helps you understand hundreds times better since you have to work through all these processes (Interview, line 93).

Prospective science teachers’ intentions to implement inquiry-based teaching practices in their classrooms in the future heavily influenced by their epistemological commitments and science learning experiences in their elementary, secondary, and undergraduate education. Although all participants were in general agreement on the
value and usefulness of inquiry-based teaching, they had practical and pedagogical hesitation about implementing such an instruction. Classroom management, time, inexperience, lack of pedagogical tools, and frustration that rises in ill-structured problem solving situations were among the issues the participants cited as reasons for their hesitation. Participants who enjoyed their experiences and were successful in this module were more willing to try inquiry teaching.

5.4 Summary

In this chapter, I have presented and discussed the results of my analysis based on research questions. In the next chapter I will present conclusion and assertions of this study along with implications for science teacher education and recommendations for further study.
Chapter 6

CONCLUSIONS & IMPLICATIONS

In this chapter I present conclusions of this study and recommendations for science teacher educators and researchers. The research questions in this study are used as an organizer for the discussion of conclusions and assertions.

The purpose of my research was to explore prospective secondary science teachers’ developing understandings of scientific inquiry and basic Mendelian genetics within the context of science education course. Instructional module was designed to create a learning environment for participants to enhance their understandings. I provided a theoretical discussion of the kinds of issues that emerge when scientific inquiry becomes the focus of a classroom, in which prospective science teachers are the students. This case study demonstrates the difficulties that participants dealt with while learning science as inquiry. The results of my study not only contribute to the limited research on prospective science teachers’ understandings of scientific inquiry and Mendelian genetics, but also confirm and extend findings reported in the literature. The findings of this study provide a positive view of carefully designed inquiry experiences, which can help learners to develop an understanding about the types of questions scientists in that field ask, the methodological and epistemological issues that constrain their pursuit of answers of those questions, and the ways in which they construct and share their explanations.
6.1 Assertions

Question 1: What is the nature of prospective secondary science teachers’ understandings of scientific inquiry and in what ways do their understandings change after engaging in guided inquiry that include constructing and testing hypotheses?

6.1.1 Assertion One: Prospective science teachers’ understandings of scientific inquiry can be enhanced through personal experiences with scientific investigations in the context of guided inquiry combined with reflection.

Participants’ understandings of scientific inquiry changed throughout the module. Initially, they did not have informed and contemporary understanding of all aspects of scientific inquiry. After the module there was a general progress across the twelve participants from less to more informed views of scientific inquiry and the nature of science. It is possible in a short amount of time to enhance prospective teachers’ understandings of scientific inquiry.

The assumption for learners’ understandings of inquiry to be modified after their personal experiences with scientific investigations can be explained by considering the situated nature of cognition (Brown & Campione, 1996; Lave & Wenger, 1991). From a social constructivist perspective learning occurs as a result of an interaction between activity, concept, and culture. Putnam & Borko (2000) asserted that from a situated cognition perspective the notion of learning as knowledge acquisition is abandoned, instead:

The physical and social contexts in which an activity takes place are integral part of the activity and that the activity is an integral part of the learning that takes place within it. (p.4)
Most of the previous research on understandings of scientific inquiry revealed that both prospective and in-service teachers possess naïve or uninformed views of the nature of scientific inquiry (Schwartz & Crawford, 2003; Windschitl, 2003). The results of the present study appear to confirm that situation. Participants’ initial views of scientific inquiry were not consistent with contemporary philosophies of science. Similar to the Murcia & Schibeci (1999) study most prospective teachers perceived science as the process of discovery in which the truth about the world is uncovered. A positivist view of science is commonly associated with the tendency to adopt a transmissive approach to teaching science (Brickhouse, 1990). Prospective teachers initially placed more emphasis on the products of science as opposed to the processes. The tentative nature of scientific knowledge was not recognized. After engaging in inquiry most participants began to consider the role of scientific processes in generating new knowledge claims.

Scientific inquiry includes processes such as generating ideas, coordinating ideas with the evidence, evaluating the findings, weighing alternatives, constructing models that could be useful for making later predictions, and asking questions. While a list of these processes certainly does not capture all of the cognitive, conceptual, procedural, and social dimensions of scientific inquiry, it does provide a view of what is currently associated with inquiry.

Participants in this study were given opportunity to form and test their hypotheses and construct explanations about coat color and pattern inheritance in domestic cats. The instructional module engaged pairs of prospective science teachers in using Mendelian concepts to make sense of inheritance pattern observed in domestic cats’ coat colors and patterns and then revise their explanations as they encounter anomalous data.
The Catlab computer software was used to generate litters of kittens, as participants formed and tested hypotheses to account for various inheritance patterns such as dominance, co-dominance, and X-linkage. At the end of the module they presented their models to the class and explained how their models could account for particular cross results. Participants’ understandings of scientific inquiry and abilities to do inquiry were separately evaluated from their understandings of domain-specific knowledge which in this case was Mendelian genetics.

After the module participants demonstrated extended expertise in their understandings of the following aspects of scientific inquiry: a) iterative nature of scientific inquiry; b) the tentativeness of specific knowledge claims; c) degree to which scientists rely on empirical data as well as broader conceptual and metaphysical commitments to assess models and to direct future inquiries; d) understanding of need for conceptual consistency; e) multiple methods of investigations and multiple interpretations of data; f) social and cultural aspects of scientific inquiry.

A community with a shared goal of individual learning is a “knowledge-building community” (Scardamalia, Bereiter, & Lamon, 1994), where individuals are committed to sharing information (data) for the purpose of building understanding in all participants. Prospective science teachers were constantly learning new skills (aspects of hypothesis testing) transforming information (data) into knowledge and knowledge into outcomes (inheritance models) through their social interactions. A learning community builds knowledge in all its participants through collaboration. However, following question still remains: how do we support such a community?
One of the ways that preliminary presentations helped prospective teachers to develop conceptual and procedural understandings is by creating an environment for participants to articulate their thinking. Pairs of participants made their understandings and predictions public. In turn, this helped them to monitor their progress and revise their inquiry strategies. Participants became aware of questions such as “Did we have enough and/or relevant evidence,” “Did we finish explaining our hypotheses,”; “Did we have a complete inheritance model.” Trying to answer such questions helped participants to evaluate their progress and frame their inquiry around articulating knowledge claims and providing evidence to support such claims. After preliminary presentations, prospective teachers started to think about “How we know what we know,” and “Did we answer our driving questions.”

Lave & Wenger (1991) described “legitimate peripheral participation” (LPP) as a process of learning within communities of practice. LPP is “a way of gaining access for understanding through growing involvements”. Learning how to learn is the requirement to enter in a community of learners. Social interactions are important not only to transmit the information but also to construct understanding collaboratively.

6.1.2 Assertion Two: When implemented carefully, hypothesis testing has a potential to support the prospective science teachers to acquire the integrated knowledge about inquiry and abilities to do inquiry.

Additionally, simulations like Catlab can be used to detect errors and gaps in conceptual understanding and problem solving strategies in the science learning process.
6.1.2.1 Abilities to Do Inquiry

Key findings included prospective teachers’ initial limited abilities to create evidence-based arguments; their hesitancy to include inquiry in their future teaching; and the impact of collaboration on thinking. In interviews several participants recognized the importance of inquiry in promoting critical thinking in classroom setting; for example Lisa said:

I do like how inquiry promotes critical thinking. Students today usually are fed cookbook labs, and using guided inquiry will help increase their critical thinking.

After generating enough data, participants inferred certain causal relations among traits and by mating selected cats they evaluated those relations. Generating meaningful relations is obviously more difficult than evaluating them later on. During the module participants became more and more sensitive about not making unwarranted knowledge claims, and they developed the ability to recognize unwarranted claims made by their peers. Participants learned Mendelian genetics concepts that enabled them to evaluate their peers’ proposed explanations about coat color and pattern inheritance.

The majority of the participants had difficulties in articulating causal claims; they often failed to cite sufficient data to support their arguments. In most cases they looked for plausibility as a sufficient criterion for justification and paid no attention to alternative hypotheses. In Rachel’s case she recognized her initial difficulty with accepting results without questioning them. The following quote from Rachel’s interview provides evidence for such behavior.

We felt comfortable with our genetics knowledge so we didn’t really question too much. If we found, like, the Chi-square fit and it fit with our
predictions we kind of just accepted it and we moved on, you know, we
didn’t really double guess.

For example, biology majors just assumed that the all-white allele was recessive
to the not-all white allele, and they did not conduct any crosses to test this claim.

According to these biology majors the reason that there were not many all-white cats in
the population, was that white had to be recessive trait. However, in reality, the all-white
allele is a dominant allele, and the only reason there were not many all-white cats is that
the all-white allele has a very low frequency in the population. In the beginning
participants often employed a plausibility standard to evaluate causal explanations. This
suggests a lack of understanding of the epistemic nature of scientific knowledge and how
data is used to support such explanations.

Reflection is essential to learning in an inquiry context. Two events appeared to
influence participants’ views. The opportunities for peer interaction and the preliminary
project presentations appeared to be critical in promoting participants’ reflection on their
data and findings. During the preliminary presentations prospective teachers received
critical feedback that could be used in subsequent inquiry.

Another tool that appeared helpful was the rubric distributed at the beginning of
the module. Criteria for scoring performance in inquiry projects were clearly emphasized
in the rubric (See Appendix F). This rubric helped to frame participants’ inquiry
assignments as hypothesis testing, by gathering and evaluating evidence and constructing
causal explanations for the data. The instructor explicitly emphasized the importance of
the reasoning process and supporting claims with data. Preliminary presentations and
regular peer review helped participants to see the data and the evidence that was used to
support particular hypotheses. Those participants who were deemed successful explicitly refuted alternative explanations, and they recorded specific limitations of their own explanations. Those participants determined to be the least successful participants acknowledged limitations, and only a few entertained and refuted alternative explanations.

The number of variables and interactions caused confusion for some participants. Some participants decided what was relevant to their investigation and tried to avoid confusion by ignoring irrelevant traits and/or patterns. The strategies that were employed by the less successful participants included: (a) no search strategy, simply guess, (b) limited search strategy leading to insufficient data, (c) irrelevant data search strategy, (d) extensive search strategy with inadequate integration and analytical skills. The successful participants, on the other hand, were more methodical in using general investigative strategies, and they tried to satisfy their argumentative goal for each step. They followed focused and targeted search strategies in their investigations. There is evidence that two pairs, Ben and Kevin from the beginning and Mary and Wilson towards the end of the module, exhibited systematic and thorough processes during their investigations.

The data suggest that Mary's approach in the inquiry project was more informed from her educational background and experience teaching at the college level. Mary frequently used hands-on activities and demonstration in her physics lab. Many of these activities were inquiry in nature where students encountered scientific phenomena and principles through observation and data gathering.

The lack of articulating causal explanations may result from the lack of conceptual understanding of the domain specific knowledge; however, in this study the
non-biology majors were more successful in articulating the causal explanations than were the biology majors. One explanation for this situation is that, apart from conceptual knowledge, there is rhetorical knowledge about what aspects of conceptual theories need to be articulated in order to construct the best explanation for the particular data. In their recent paper (Sandoval & Reiser, 2004) explained how epistemological commitments influence processes of scientific inquiry and deriving from the theories of the nature of scientific knowledge they introduced the concept of general argumentative knowledge.

One aspect of hypothesis testing involves a confirmatory versus disconfirmatory approach to inquiry. Peter Wason’s (Newstead & Evans, 1995) work on hypothesis testing and experimentation strategies yielded that people tend to be biased towards confirming current theories, rather than disconfirming them. Following Wason’s work Klahr et al. (1993) investigated the effect of the initial belief in developing and testing hypotheses. When a student’s initial belief in the given hypothesis is high, he/she tends to devise experimental cases to confirm the hypothesis. When a student’s initial belief is low, he/she explicitly tries to disconfirm the given hypothesis. A confirmatory strategy is not an unreasonable strategy for testing hypotheses, even when the goal is to disconfirm. Schauble et al. (1991) reported that in inquiry, the more successful subjects were more methodical in their experimentation. Specifically they manipulated fewer variables, holding variables constant while one was systematically explored, and they pursued controlled experimentation, until they were able to generate sufficient evidence to infer a variables’ role in the system.

In this study the participants who were consistently and actively engaged in Catlab inquiry activities developed more expert-like scientific inquiry abilities. It is
impossible to state unequivocally that all of the changes in inquiry understanding that were identified were a direct result of the Catlab module. However, it is reasonable to assume that the module contributed to those changes. Therefore, I conclude that activities including constructing and testing hypotheses and explicit instruction have the potential to support prospective science teachers in developing more sophisticated understandings of scientific inquiry.

Question 2: What are prospective secondary science teachers’ understandings of Mendelian genetics and to what extent, if at all; did participants develop understandings about concepts of Mendelian genetics?

6.1.3 Assertion Three: Most prospective teachers, even biology majors, possess weak conceptual understanding of Mendelian genetics and have a simple, mechanistic understanding of gamete combination and probability.

Initially prospective secondary science teachers, including prospective biology teachers, did not demonstrate conceptual and procedural understandings of Mendelian genetics concepts. Participants’ understandings of Mendelian genetics were enhanced after the module.

In the genetics pre-test 10 out of 12 participants correctly responded to less than 50% of the questions. The genetics pre-test revealed that most of the participants, even the biology majors, did not have strong conceptual understanding of Mendelian genetics, and they had a very mechanistic understanding of gamete combination and probability at the beginning of the module. The concept of probability seemed the most difficult one for them to grasp. They also had some difficulty with understanding the basic terminology associated with basic Mendelian genetics. Interestingly, almost all of them knew how to
make and use a Punnett square; however, the conceptual knowledge and cognitive operations behind the Punnett square were mostly absent. Most of them used a Punnett square without having a conceptual understanding of it; even after the module. They showed some expertise in testing hypotheses after the module. Every one of the pairs came up with well substantiated answers to their driving inquiry questions.

The results of this study indicate that the science learning environment designed in the Catlab module supported the participants’ conceptual elaboration of Mendelian inheritance. The analyses of the participants’ pre- and post-tests suggest that there were qualitative changes in the nature of the participants’ explanations. Moreover, the average percentage of correct responses in pretest was 39%. Surprisingly, the biology majors’ average percentage (38%) was not higher than the average percentage for participants majoring in other disciplines (40%). In spite of their extensive coursework in biological sciences, the biology majors lacked a deep conceptual understanding of Mendelian genetics. The average percentage of correct responses improved from 39% on the pre-test to 67% on the post-test.

The framework for the instruction included a project-based design in which the inquiry projects were driven by the goal of constructing an inheritance model for coat color and pattern in cats. This allowed participants to develop a general epistemic understanding of scientific knowledge. They produced models that represented their understanding of the problem and after applying evaluation criteria to their own explanations they presented their models to their peers. During the module the participants had to explain the genes that control the specific traits and alleles for each gene and interactions between alleles. The participants were required to be reflective and
metacognitive during each step of the investigation. Reflection is essential for learning in inquiry context. It appeared that communication within pairs and between pairs, as well as the preliminary presentations, fostered substantial reflections from participants about other pairs’ and their own investigations. However, the final presentations were not as effective in engaging participants in critical discussions and reflections. During the final presentations the participants believed they had already provided a great deal of critical feedback during the module and in preliminary presentations.

The finding that goal orientation and epistemological beliefs are factors that impact learning strategies is consistent with research done with high school students learning genetics concepts such as meiosis and use of Punnett square method of analysis (Cavallo, 1996). This finding stems from the observation of characteristics of successful and the least successful participants, and it connects with the practices associated with participants’ different goals.

Gott & Duggan (1996) suggested that understanding the relationship between evidence and theory is essential for developing informed views of scientific inquiry. They claimed that understanding the evidence requires a higher level of understanding than simply carrying out the procedures. Their assertion is consistent with Schauble, Klopher, & Ragahavan’s (1991) report in which they describe the relationship between understanding evidence and understanding the goals of experimentation. Schauble, Klopher, & Ragahavan (1991) reported that if learners focus on the products of experiments rather than the processes that produced the outcomes with the purpose of getting particular answers, then a methodical evaluation of the evidence is abandoned and learners often fail to consider alternative hypotheses. Results of this study confirm their
findings. Biology majors, in particular, tended to generate and accept faulty evidence consistent with their prior knowledge.

Reflection, analysis, and evaluation are crucial to inquiry-based learning. One of the most significant differences in the behavior of the successful versus less or the least successful participants is a further reflection of the diverse problem solving heuristic. The least successful participants did not engage in a larger number of random search activities, but in a larger percentage of those activities. They generated as much preliminary data as their successful peers, but were unable to utilize the data in meaningful ways to test hypotheses. They ended their experiments with an arbitrary conclusion for which there was no direct evidence. Successful participants never felt like they completed their investigations; they kept testing and considering alternative hypotheses. Inquiry-based teaching and learning supports three types of knowledge acquisition (Krajcik, Czerniak, & Berger, 1998). These are (a) content knowledge, (b) knowledge of inquiry and problem solving, and (c) epistemic knowledge. Knowledge of inquiry and problem solving refers to recognizing how to solve a problem, design, and perform investigations and employ metacognitive strategies. Epistemic knowledge refers to knowing what counts as evidence and when to collect more evidence to support/refute a hypothesis. Epistemic cognition is especially important for solving ill-structured problems. While discussing pedagogical principles for inquiry-based learning Duschl, Ellenbogen, & Erduran (1999) suggested organizing inquiry-based learning around conceptual, social, and epistemic objectives. Social aspects include communication and representation of scientific ideas and knowledge claims. Peer evaluation makes
epistemological ideas explicit and debate ignites reflection and re-evaluation of these commitments.

The participants’ learning in this study included the processes of generating qualitative and quantitative relationships between traits, evaluating the empirical consistency of the relations between genes by examining phenotypes of the offspring, and modifying these relationships according to interpretation of the data gathered. In addition, participants encountered discrepant information in Catlab and expressed their surprise when they discovered that a particular relationship was not valid. Participants were observed designing a new test based on discrepant information to confirm their findings.

Although the research base related to discourse in science classrooms is growing, still little is known about hypothesis testing, and explanation-building processes in learner-centered small-group learning environments. While there were a number of variables including the nature of participants, the classroom setting, participants having other course experiences, and the computer software, which may have influenced the enhancement in understandings and process skills, one of the contributing factors influencing knowledge gains may have been the specific instructional approach used in the Catlab module. One positive finding of this study is that the use of a simulation such as Catlab has the potential to provide an excellent context to enhance domain specific knowledge in science. Additionally, it creates an environment for the discussion and debate about aspects of scientific inquiry. One important issue that emerged is that understanding the goals of investigation and the role of evidence appear critical to understanding scientific inquiry.
Question 3: (a) From the learners’ perspective, what were the instructional strategies and classroom interactions in this module that contributed to their understandings of scientific inquiry and Mendelian genetics as well as to development of abilities to do scientific inquiry? (b) What were the prospective teachers’ intentions to use inquiry in their own classrooms in the future?

6.1.4 Assertion Four: Immersion of prospective science teachers’ as learners of science and in metacognition served as a powerful tool for thinking about the role of inquiry in teaching and learning science.

While their developing understandings of teaching science as inquiry are still far from appropriate, these prospective teachers appeared headed in the right direction to realize the vision of reform documents. Yet, the interaction between prospective teachers’ views of science and teaching science demands additional research.

In addition to engaging in fundamental processes commonly associated with scientific inquiry, participants also engaged in more complex processes, such as coordinating data with theory. One pair encountered disconfirming information and attempted to coordinate this new information with their developing hypotheses on gene interactions; postulating a hidden causal factor to explain discrepant information; using analogies to support explanatory models. As anticipated by Howe et al. (2000), guidance and peer interaction during inquiry seem to be necessary to ensure an adequate performance with predicting, observing, and concluding. An important pedagogical strategy is to engage the learners in scientific inquiry, i.e. performing and interpreting experiments for the specific purpose of verifying or revising theories and explanations, and communicating and negotiating them with peers (Kelly & Chen, 1999). The results
of this study show that hypothesis testing can be used to support the integrated acquisition of conceptual and procedural knowledge in science. In order to support the acquisition of conceptual and procedural knowledge within a community of learners via hypothesis testing, participants should be encouraged to debate their conceptual knowledge, and their consensual positions should be evaluated collectively, and conclusions should be drawn as a result of evaluation. However, in the context of community of learners, participants did not merely learn through a hypothesis testing exercise; metacognitive as well as cognitive engagement with the assignment and events that were occurring in classroom also facilitated this learning.

Socially constructed processes like negotiation, consensus, and collaboration with peers and the instructor played a very important role in directing cognition and triggering individual reflection. Guidance from the instructor and peers who had more expertise was also invaluable in developing understandings about inquiry processes and Mendelian genetics concepts. Debate facilitated learning conceptual knowledge, while peer interaction and guidance nurtured procedural knowledge.

Findings also suggest those prospective teachers’ experiences as learners of science in this course served as a powerful tool for thinking about the role of inquiry in teaching and learning science. Based on their own experiences as learners, prospective science teachers tried to figure out how inquiry approach can be used in their future classrooms. In general, participants associated scientific inquiry with questioning and acknowledged it as a means of engaging students cognitively in science learning. In becoming familiar with hypothesis testing through their personal experience with inquiry, they gained an appreciation or value for engaging their future students in scientific
inquiry. They become aware of possible difficulties and frustrations that their future students will encounter.

Teachers’ guidance strategies played a critical role for participants to engage in processes of inquiry. Generating ideas about inheritance pattern, constructing explanations, quantitative problem solving, and reasoning processes as they interacted with teacher and each other, helped participants to develop abilities to do inquiry. Teacher guidance strategies included: asking participants to compile data from Catlab, asking them to find patterns and trends, and providing discrepant information. Associated with these activities working back from the data, controlling more variables, asking why questions, designing a new test, and evaluating and modifying relationship in the light of new information were among scaffolding strategies. Small group discussions and competition among pairs has been linked with positive impact for participation and achievement.

Participants had mixed views when asked about their willingness to enact inquiry in their teaching in the future. All of them stated some kind of general willingness to do so; yet, they also mentioned some reservations and practical considerations about inquiry-based teaching. Some participants’ perspective was that inquiry is a time consuming endeavor and incompatible with the amount of content they are required to cover. Prospective teachers mentioned the following barriers to implementing an inquiry-based approach to science teaching and learning: (a) lack of effective models in their experiences, (b) lack of curriculum materials, (c) assessment issues, (d) lack of time.

Fundamental processes of scientific inquiry can be demonstrated, exercised, and incorporated into instruction by employing technology tools, such as Catlab. Being able
to generate data and build relationships between variables, make predictions, form hypotheses and test them, and to construct and modify scientific models that can explain and account for data. All these activities helped to engage prospective science teachers in science as inquiry. The technological tool used in this module not only provided a context for carrying out an inquiry activity and learning about Mendelian genetics content, but also presented an example for prospective science teachers on how to use such a tool in their future classrooms.

6.2 Implications for Science Teacher Education

This study engaged prospective secondary science teachers in opportunities to enhance and develop their knowledge and use of inquiry through guided inquiry activity designed to increase their understanding of Mendelian inheritance concepts. This combination of modeling inquiry-based teaching and the development of science concepts intended to address some of the problematic issues in science teacher education. Prospective science teachers were provided both the techniques and the conceptual understanding necessary to provide inquiry-based science experiences for their students in the future.

The present study offers valuable insights into the preparation of science teachers as well as for future research on learning science. Important issues emerge for science education programs to support the development of science teachers who are equipped with abilities to implement current vision of reform in science education into their classrooms. Prospective science teachers need to engage more in inquiry-based teaching experiences early in their preparation, in order to develop understanding of scientific
inquiry; and to build the cognitive and procedural skills necessary to implement such teaching in their own practices in the future. “None of us really used to do anything like that. Until now it has always been very structured research experience that is another reason that this experience was valuable.” Interviews and questionnaires support Schwartz & Crawford’s (2003) claim of a lack of inquiry based experiences in science teacher education.

The findings of this study suggest that, most of the prospective science teachers lacked a sound background as a scientist. Prospective biology teachers, despite their assumed stronger background in content, were no more successful than other participants. There could be several contributing variables; one possible reason could be the way each problem was presented. Both pairs who majored in biology were working on problem number one, which was probably the most comprehensive question. Although as one other participant articulated “all questions came to: who can explain inheritance pattern in cats?” Pairs of participants who focused on other questions were relatively more successful in their investigations. Therefore, the difficulty level of the inquiry task should be in accordance with the learners’ ability and understanding level. Another explanation for the poor performance could be attributed to cognitive deficiencies. Taking Lave & Wenger’s (1991) and Brown & Campione’s (1996) advice, looking at the extent to which our participants became part of communities of practice that value the use of data, evidence, testing, and peer’s findings. Communities, in which prospective teachers negotiate, construct argumentations, and practice persuasion could have positive effects on learners’ knowledge. In the beginning those prospective biology teachers who considered themselves experts, not only failed to pay attention to their peers’ findings,
but also failed to test their hypotheses adequately using Catlab. In this case some jumped
to a conclusion and made claims with no supporting evidence. Therefore, when they were
presented with many discrepant events, they were confused, frustrated, and lost their self-
confidence. The implication is that to support prospective teachers’ conceptual and
procedural knowledge about science content as well as scientific inquiry within an
inquiry based module, it is advised: (a) give opportunities for debate about their
conceptual knowledge, (b) subject their consensual positions to testing, (c) press them to
reach a consensus and draw conclusions.

The National Science Education Standards recommend that students develop
understandings about and abilities to do scientific inquiry (NRC, 1996). In Science for
All Americans (1990), it is stated that “Teaching should be consistent with the nature of
scientific inquiry.” Curriculum reform, as the aforementioned documents suggest, could
only be successful when our prospective and in-service teachers become a part of such a
community where they share experiences with their colleagues and value the construction
of knowledge by observing patterns and building support for one’s claim.

Change is difficult and it requires time. Considering that four weeks is a short
period of time in relationship to ones college career, participants demonstrated
noteworthy progress. As in previous research (Windschitl, 2003), this study suggests that
prospective science teachers need to engage more in inquiry-based teaching experiences;
and to build the cognitive and procedural skills necessary to implement such teaching in
their own practices in the future. As Borko and Putnam (1995) suggest, teacher
knowledge structures are both the objects and vehicles of change, hence, engaging
prospective science teachers in learning science and scientific inquiry via inquiry-based
teaching is very important. Such an approach provides fertile ground for them to develop
the ability to teach in a manner consistent with the vision of the standards.

The National Science Education Standards (1996) emphasize the use of inquiry-
based investigations as a means of effective science teaching and learning. Teachers need
knowledge, skills, and resources that enable them to implement inquiry-based teaching
effectively. It is difficult to envision how future teachers can be expected to implement
the inquiry standards efficiently without experiencing inquiry-based instruction as a
learner themselves. Prospective science teachers are rarely exposed to direct experience
of scientific inquiry in their science and science education courses through which they
could develop skills needed to facilitate inquiry-based learning for their students in the
future. The type of experiences provided for prospective teachers during their preparation
should actively engage them and model the type of teaching intended for their future
classrooms. When teachers have learning experiences that engage them in inquiry, they
will more likely involve their students in similar inquiry experiences.

Science teacher education programs should incorporate the following concerns
into their curriculum: (a) engaging prospective teachers in peer review, (b) integrating
varied learning environments, (c) having prospective teachers reflect on action and
interaction, (d) engaging prospective teachers in collaborative science teaching and
learning practices.

6.3 Limitations of the Study

There are several limitations of this study. First of all, the results of this
investigation may not be generalized beyond these participants. Secondly, the complexity
of research setting and the interactions prevents pinpointing the factors affecting the learning. Most of the participants were also enrolled in SCIED 411 course, which covers issues related to scientific inquiry and nature of science. Change in participants’ understandings may very well influenced by their experiences in other courses. There is no way to be completely sure if understandings improved and changed as a result of experiences that occurred during the module. My instructional goals were to support the prospective science teachers in learning about the scientific inquiry and Mendelian genetics concepts. Most of the participants began with uninformed views of the different aspects of scientific inquiry that most likely resulted from their own experiences in school and college.

I did not provide direct instruction about Mendelian inheritance; participants had different backgrounds and very limited inheritance knowledge. Further study is needed to explore the same issues with participants of more homogeneous backgrounds. It will also be interesting to see how results would be different if focus of the module was to teach genetics. Another limitation is the fact that, although there was support and contribution from the committee and advisor, there was only one researcher who designed the study, performed the data collection, and prepared, interpreted, and analyzed the data.

Data in this study were limited to pre- and post-questionnaires, participants’ artifacts during the module, participants’ background, and interviews with selected participants. Methodological limitation included not having pre-interviews. Questionnaires did not provide extensive information about participants’ prior knowledge.
Another limitation stems from the fact that participants worked in pairs, and I tried to assess individual understandings and abilities using project reports, presentations, and my observations and interactions with them. Although it is worth mentioning, this limitation did not prevent me from addressing my research questions. Testing and treatment interaction also raises concerns in interpreting results of this study.

Finally, it is important to mention my dual role of instructor and researcher. The issue of interviewing the students, and the possibility that some may have skewed some of their responses in order to please me, must be raised.

6.4 Recommendations for Further Research

In the science education community, we value the development of knowledge, abilities, and attitudes that are unique to scientific inquiry. Since learners’ perceptions and attitudes in inquiry environments greatly influenced by teachers’ expectations and assessment practices. Therefore, further research should focus on designing, developing, and implementing appropriate assessment tools and techniques into school science curriculum.

Prospective science teachers’ epistemological orientations play a crucial role in their intended teaching practices. Parallel to their experiences during their K-12 and undergraduate education, prospective science teachers develop epistemological commitments. Beliefs about the nature of knowledge, nature of science and teaching science emerge as important elements in intentions to implement inquiry practices in their teachings; therefore we need more studies exploring these issues.
Further research is needed to understand how socially supported processes emerge and can be sustained in the science classrooms. In collaborative inquiry, learners make their ideas public, open to discussion; they engage in social interactions such as debating and forming consensus. Epistemological practices are also become topic of conversations. Epistemic practices are defined as the reasoning and discursive practices involved in making and evaluating the scientific knowledge (Sandoval & Reiser, 2004). One important research goal arising out of curriculum design work is the opportunity it provides to study school science-in-the-making (Kelly & Chen, 1999), in other words the epistemological aspect of the school science.

Without a doubt, computer technologies are useful and valuable in improving the level of science teaching. Yet, the question “What are the most effective ways for science teachers to enhance students’ learning of science using computer technologies?” still needs an answer. In this study, my goal was not to evaluate the effectiveness of Catlab simulation in learning Mendelian genetics. Another study can focus on Catlab as an instructional tool in high school and/or undergraduate biology courses. I regard computer simulations as important tutorial tools, however; some problems could arise with the general excitement about using computer technologies at all levels of science education.

In science education community, we need an array of research studies to enhance understanding of inquiry-based teaching and learning in all scientific disciplines. Helping prospective science teachers to develop informed views of scientific enterprise and abilities to sustain inquiry-based teaching practices remain significant for science education reform. Additionally, we need more research studies to support conceptual learning in high school and undergraduate biology. This study arises numerous relevant
research questions based upon the observation of learners interacting with Catlab in the context of the community of learners. Possible questions include:

- How do learners apply Mendelian genetics principles (such as probability) to situations where they must interpret and analyze data (such as genetic ratios) and explain unexpected data within the context of their hypotheses?
- How to initiate conceptual change and support meaningful learning in: a) the connection between meiosis, independent assortment, and segregation; b) the connections between probability and the outcomes from litters of offspring; c) the connections between predicted genetic ratios and actual ratios.
- How can we best use technology to support learning in science?

In order to increase our understanding of collaborative inquiry, we need to develop analytical tools which offer a process-oriented account on collaborative science learning and analyze the relationship between communicative and cognitive components of such a discourse. Following question could be a focus of the next study: What are the essential elements of the instructional environment that engages the students in the authentic practice of science, i.e. performing and interpreting experiments for the specific purpose of verifying or revising hypotheses and explanations, and communicating and negotiating them with each other?

Findings of this study appear positive, yet we do not know the lasting impact from such a limited experience. Longitudinal research studies are needed to fully understand the effect and durability of such experiences over time.
BIBLIOGRAPHY


Appendix A

Informed Consent Form for Behavioral Research Study the Pennsylvania State University

Title of the Project: Supporting Prospective Teachers’ Understanding of Inquiry and Genetics Using CATLAB

Principal Investigator: Mustafa ÇAKIR, mxc446@psu.edu
Other Investigators: Barbara A. Crawford, PhD, bac21@psu.edu
William S. Carlsen, PhD, wcarlsen@psu.edu

1 This section provides an explanation of the study in which you will be participating:

A The purpose of this study is to explore the prospective science teachers’ understandings of scientific inquiry and their understanding of basic Mendelian genetics and the effect of instruction and experiences on those understandings. By conducting this research we hope to better understand how to support our students’ understandings in scientific inquiry and science content.

B If you agree to participate in this study, the investigators will keep copies of selected assignments for further examination. In addition, you will be asked to participate in one interview lasting approximately one hour during the course of this semester and your interaction with the computer simulation may be videotaped in class.

C With the exception of the interviews, your participation in the study will not extend beyond your normal involvement in the course. That is, there will be no additional requirements associated with course projects/assignments if you agree to participate in the study.

D If you do not want to participate in this research, you will still be required to complete course projects/assignments; however, your work will not be used in the study.

E This study will involve audio and video recording. Only the investigators will have access to these tapes. Tapes will be stored in locked filing cabinet in 156 Chambers building. All audio and videotapes will be destroyed after a period of 5 years.

F Benefits of this study are two fold; participants may gain insights into their own levels of knowledge regarding science inquiry and might realize their level of
preparation to teach science and gain confidence in their abilities. On the other hand, through the research, science educators will understand the positive and negative impacts of this project and be able to gauge their success in improving the instruction of science education in secondary science teacher preparation.

2 This section describes your rights as a research participant:

A You may ask any questions about the research procedures and these questions will be answered. Further questions should be directed to Mustafa ÇAKIR.

B Your participation in this research is confidential. Only the person in charge and other investigators on this project will have access to your identity and to information that can be associated with your identity. In the event of publication or presentation of this research, no personally identifying information will be disclosed.

C Your participation is voluntary. You are free to stop participating at any time or to decline to answer specific questions without penalty.

D This study involves only minimal risk, that is, no risk to your physical or mental health beyond those encountered in the normal course of everyday life.

E If you decide not to participate, it will not be disclosed to the person responsible for grading until after grades have been submitted at the end of the semester.

F If you have questions about your rights as a research participant, contact Penn State’s Office of Research Protections at (814) 865 1775.

3 This section indicates that you are giving your informed consent to participate in the research:

I agree to participate in a systematic investigation of supporting prospective science teachers’ understandings of scientific inquiry and basic Mendelian genetics, as an authorized part of the education and research program of The Pennsylvania State University. I understand the information given to me and have received answers to any questions I may have had about the research procedure. I understand and agree to the conditions of this study as described. To the best of my knowledge, I have no physical or mental illnesses/difficulties that would increase the risk to me by participating in this study. I understand that I will receive no compensation for participating, and that my grade in the course will not be altered by my participation. I understand that my participation this research is voluntary, and that I may withdraw from the study at any time by notifying the person in charge. I am 18 years of age or older. I understand that I will receive a signed copy of this consent form.
I, the undersigned, verify that the above informed consent procedure has been followed, and that I have answered any questions from the participant above as fully responsible.
Appendix B

Mendelian Genetics Concepts Pre-test

Name:

1. Write a definition of what the term “genotype” means.

2. Write a definition of what the term “phenotype” means.

A black cat is crossed with a grey cat, and a litter of 6 black and no grey kittens is produced.

3. What can you conclude about the genotypes of the parents?

4. Upon what reason(s) do you base your conclusion?

5. How could you determine the genotypes of the parents?

6. How could you determine the genotypes of the offspring?

The kittens (from problems 3-6) mature and you cross two of the six black cats from the litter. Their offspring are 3 black and 1 grey kittens.

7. What can you conclude about the genotypes of the two black cats which you crossed (the kittens’ parents)?
8. Upon what reason(s) do you base your conclusion?

9. What can you conclude about the genotypes of the grandparents (which were black and grey)?

10. Upon what reason(s) do you base your conclusion?

11. In a cross between a homozygous, red-eyed female fruit fly and a white-eyed male, what percent of the male offspring will have white eyes? (White eyes are X-linked, recessive). Show your work.

   a. 100%   b. 75%   c. 50%   d. 25%   e. 0%

12. In human beings, brown eyes are usually dominant over blue eyes. Suppose that a blue-eyed man marries a brown-eyed female whose father was blue-eyed. The percentage of their children with blue eyes would be closest to _______. Show your work.

   a. 0   b. 25   c. 50   d. 75   e. 100
Appendix C

Mendelian Genetics Concepts Post-test

Name:………………………..

1. Mackerel tabby is crossed with another mackerel tabby; a litter of two blotched tabby kittens produced. One of the blotched tabby kittens is crossed with another blotched tabby cat. Four blotched tabby kittens are produced.

These results would indicate that (check the best answer):

_____ a) mackerel tabby is dominant to blotched tabby

_____ b) blotched tabby is dominant to mackerel tabby

_____ c) neither blotched nor are mackerel dominant to each other

_____ d) not enough information is available to determine which one is dominant or recessive

2. I choose my answer to #1 based on:

3. If 10 crosses between two mackerel tabbies (same parents each time) produced only mackerel tabby kittens, we could conclude that:

_____ a) mackerel tabby is a recessive trait

_____ b) mackerel tabby is a dominant trait

_____ c) mackerel tabby may be dominant or recessive

_____ d) mackerel tabby does not follow the principles of Mendelian genetics
4. If one of the blotched tabbies is crossed with a mackerel tabby, the offspring will have:
   
   _____ a) striped bodies
   _____ b) bodies with whorled areas
   _____ c) striped heads and backs with a whorled belly
   _____ d) choice a and/or b
   _____ e) choice b and/or c

5. Write the definition of what the term “phenotype” means?

(For questions 6-9)

A black cat is crossed with a grey cat, and a litter of six black and no grey kittens is produced.

6. What can you conclude about the genotypes of the parents?

7. Upon what reasons do you base your conclusion?

8. How could you determine the genotypes of the parents?

9. How could you determine the genotypes of the offspring?
10. In a parakeet population, you notice an unusually high number of birds with blue colored wings, compared to a much lower number of birds with green colored wings. You decide to investigate this characteristic. What are two hypotheses (questions) you could formulate about blue and green colored wings in parakeets?

(a)

(b)

11. You notice another characteristic in the parakeet population; orange bellies and white bellies. How would you determine if white belly is dominant to orange belly?

_____ (a) cross an orange bellied parakeet with a white bellied parakeet

_____ (b) cross an orange bellied parakeet with an orange bellied parakeet

_____ (c) cross a white bellied parakeet with a white bellied parakeet

_____ (d) all of the above

12. For this problem only, we will assume that orange belly is dominant to white belly. You cross an orange bellied parakeet with a white bellied parakeet and get three orange and 3 white bellied offspring. If you cross one of the orange bellied offspring with a white bellied parakeet (not related), you predict that:

_____ (a) the chicks will be orange bellied

_____ (b) the chicks will be white bellied

_____ (c) two of the chicks will be orange bellied and two of them will be white bellied

_____ (d) the chicks may be orange bellied or white bellied
13. Upon what reason(s) do you base your choice to #12?

(For questions 14-17)

The kittens (from problem 6-9) mature and you cross two of the six black cats from the litter. Their offspring are three black and one gray kitten.

14. What can you conclude about the genotypes of the two black cats which you crossed?

15. Upon what reasons do you base your conclusion?

16. What can you conclude about the genotypes of the grandparents (which were black and gray)?

17. You decide to cross a grey cat with a black cat (unrelated to any of the cats mentioned so far). They produce a litter of four grey kittens only. How do these data affect your hypothesis about the black and gray trait? Please explain.

18. Write the definition of what the term “genotype” means?
Appendix D

Views of Science Inquiry Questionnaire

Your name ______________________________

The following questions are asking for your views related to science and scientific investigations. There is no right or wrong answer.

Please answer each of the following questions. You can use all the space provided to answer a question and continue on the back of the pages if necessary.

1. What types of activities do scientists do to learn about the natural world? Be specific about how they go about their work.

2. What scientists choose to study and how they learn about the natural world may be influenced by a variety of factors. How do scientists decide what and how to investigate? Describe all the factors you think influence the work of scientists. Be as specific as possible.

3. (a) Write a definition of a scientific experiment?
   
   A scientific experiment is…….

   (b) Give an example from something you have done or heard about in science that illustrates your definition of a scientific experiment.

   (c) Explain why you consider your example to be a scientific experiment.

4. Some people have claimed that all scientific investigations must follow the same general set of steps or method to be considered science. Others have claimed there are different general methods that scientific investigations can follow.

   (a) What do you think? Is there one scientific method or set of steps that all investigations must follow to be considered science? Circle one answer:

   • Yes, there is one scientific method (set of steps) to science.
• No, there is more than one scientific method to science.

If you answered “yes,” go to (b) below.
If you answered “no,” go to (c) below.

(b) If you think there is one scientific method, what are the steps of this method?

(c) If you think that scientific investigations can follow more than one method, describe two investigations that follow different methods. Explain how the methods differ and how they can still be considered scientific.

5. (a) If several scientists, working independently, ask the same question (for example, they all want to find out what Oregon looked like 10,000 years ago, or what the structure of a certain protein is), will they necessarily come to the same conclusions?
Explain why or why not.

(b) Does your response to (a) change if the scientists are working together? Explain.

6. (a) If several scientists, working independently, ask the same question and follow the same procedures to collect data, will they necessarily come to the same conclusions?
Explain why or why not.
(b) Does your response to (a) change if the scientists are working together? Explain.

7. What does the word “data” mean in science?
(b) Is “data” the same or different from “evidence”? Explain.

8. (a) What is “data analysis”?
(b) What is involved in doing data analysis?

9. Students in a science class investigated the relationship between size and strength of rubber bands. The strength of the rubber band was determined by the amount of weight
the rubber band could hold without breaking. The rubber bands differed only in length. Four groups of students tested six different lengths of rubber bands (2 in, 3 in, 4 in, 5 in, 6 in, 7 in) for relative strength. For each group, the amount of weight a rubber band could hold increased with the length of the rubber band. Each group stated their conclusions and reasons below. Evaluate their claims and explain the strengths and weaknesses of each as *scientific* arguments.

a) **Conclusion:** The larger rubber bands we tested are stronger than the smaller rubber bands we tested.
   
   **Evidence:** The larger rubber bands held more weight.
   
   Is this a good scientific argument or not? Explain.

b) **Conclusion:** The larger the rubber band we tested, the stronger the rubber band was, compared to rubber bands of smaller size.
   
   **Evidence:** The tests showed that, on the average, the larger the rubber band, the more weight it could hold without breaking.
   
   Is this a good scientific argument or not? Explain.

c) **Conclusion:** Larger rubber bands are stronger than smaller rubber bands.
   
   **Evidence:** The small rubber bands didn't hold much weight.
   
   Is this a good scientific argument or not? Explain.

d) **Conclusion:** The larger the rubber band we tested, the stronger the rubber band was.
   
   **Evidence:** The larger rubber bands stretched a lot more.
   
   Is this a good scientific argument or not? Explain.
Appendix E
Driving Questions for Inquiry Projects

Catlab provides many opportunities for exploring questions and problems in heredity. You may wish to pursue the exploration of other characteristics in Catlab than those presented here. Once you decide on your own inquiry problem, please discuss it with me before starting to do it. We would encourage you to pursue your inquiries.

1. Investigate and determine the inheritance pattern of the orange tabby striping trait in cats. Generate as much as data as you feel is necessary to support your conclusions about the inheritance pattern. Record your data and present it in your final presentations.

2. A cat breeder claimed that the mating of two tabby cats could occasionally produce a non-tabby kitten, but that the mating of two non-tabby cats apparently never produced a tabby kitten. Do you agree with the breeder’s observation? Can you suggest an explanation for your observations?

3. Some conditions are lethal in the homozygous state, for example yellow coat color in mice. Does this also apply to all-white coat color in cats? Use CATLAB to explore the inheritance of all-white coat color. Propose a genetic explanation consistent with the results you obtain.

4. A student set up the cross:
   Grey blotched tabby female x Cream blotched tabby male
   ad obtained a large number of kittens. The student observed that no cream blotched female kittens appeared among the offspring and concluded the only explanation was that these females died in uterus. Is the student correct? Use CATLAB to explore this situation and attempt to formulate a genetic model to explain the result observed by the student.
## Appendix F
### Secondary Science Inquiry Scoring Guide (Students' Version)

**CONNECTING**
How well do I link knowledge and experiences with established science ideas in order to construct a testable question or hypothesis?

<table>
<thead>
<tr>
<th></th>
<th>NO EVIDENCE</th>
<th>DEVELOPING</th>
<th>PROFICIENT</th>
<th>EXEMPLARY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Organization and clarity of personal understanding about related science content*</td>
<td>1. There is little or no evidence of:</td>
<td>1. I talk about, list, and/or draw what I've learned through experiences and explorations about science ideas related to this content in a confusing or unorganized way.</td>
<td>1. I discuss and/or draw and label pictures of what I've learned through experiences and explorations about science ideas related to this content in an organized and understandable form.</td>
<td>1. I creatively or elegantly organize and explain or illustrate what I've learned through experiences and explorations about related science content.</td>
</tr>
<tr>
<td>Discussion and reasoning behind observations, connections, and relationships</td>
<td>2. My observations or reasoning about related science content</td>
<td>2. I provide limited or fragmented descriptions, observations, or connections of science ideas.</td>
<td>2. I describe my personal understanding of related science content through detailed observations and connected science ideas.</td>
<td>2. I discuss and give reasons for my personal understanding of related science content by richly describing observations, connections between observations, and relationship between variables.</td>
</tr>
<tr>
<td>Quality and testability of question or hypothesis</td>
<td>3. A question or hypothesis that could lead to an investigation</td>
<td>3. I construct a general question or hypothesis that only hints at some kind of test.</td>
<td>3. I construct a specific testable question or hypothesis.</td>
<td>3. I construct a specific and challenging or creative testable question or hypothesis.</td>
</tr>
<tr>
<td>Connections between experiences or explorations and the question or hypothesis</td>
<td>4. Connections between what I know and what I want to know</td>
<td>4. I provide some evidence that my question or hypothesis is related to some of my experiences or explorations.</td>
<td>4. I discuss the connection between some of my experiences or explorations and my question or hypothesis.</td>
<td>4. I suggest compelling reasons for a connection between my personal understandings and my question or hypothesis.</td>
</tr>
</tbody>
</table>

**DESIGNING**
How well do I design a plan to guide an investigation, provide an explanation, or resolve a problem?

<table>
<thead>
<tr>
<th></th>
<th>NO EVIDENCE</th>
<th>DEVELOPING</th>
<th>PROFICIENT</th>
<th>EXEMPLARY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Logic and detail of the plan to answer the question</td>
<td>1. My plan makes some sense but a person trying to follow it would be somewhat confused.</td>
<td>1. My plan makes sense and can be followed by others without inferring.</td>
<td>1. My plan is logical and repeatable, such that a person following my procedures would get results similar to mine.</td>
<td>1. My plan is logical and repeatable, such that a person following my procedures would get results similar to mine.</td>
</tr>
<tr>
<td>Organization and clarity of the plan</td>
<td>2. I provide sketchy or limited evidence of an organized and workable plan to collect data.</td>
<td>2. I organize a detailed and workable plan with clear procedures in order to collect data to answer my question or hypothesis.</td>
<td>2. I organize a detailed and workable plan with clear procedures in order to collect data to answer my question or hypothesis and I explain reasons for those procedures.</td>
<td>2. I organize a detailed and workable plan with clear procedures in order to collect data to answer my question or hypothesis and I explain reasons for those procedures.</td>
</tr>
<tr>
<td>Depth of understanding of controlled variables</td>
<td>3. My design shows an inconsistent or limited understanding of controlling variables.</td>
<td>3. My design shows a general understanding of controlling variables.</td>
<td>3. My design provides clear evidence and reasoning of the importance of controlling variables.</td>
<td>3. My design provides clear evidence and reasoning of the importance of controlling variables.</td>
</tr>
</tbody>
</table>

*Science "content" used throughout this scoring guide to mean the science concepts, content standards, or benchmarks that are the focus of this inquiry.

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### INVESTIGATING

**How well do I carry out the procedures of a plan to collect and organize data?**

<table>
<thead>
<tr>
<th>NO EVIDENCE</th>
<th>DEVELOPING</th>
<th>PROFICIENT</th>
<th>EXEMPLARY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alignment between procedures of plan and data</td>
<td>There is little or no evidence of:</td>
<td>1. My data were inconsistent with the procedures described in my plan.</td>
<td>1. I follow the procedures of my plan in order to collect data so that my data were mostly consistent with those procedures.</td>
</tr>
<tr>
<td>Organization and completeness of data</td>
<td>1. Data that I collected</td>
<td>2. A person would have to ask me questions in order for my data to be understood.</td>
<td>2. I recorded and represented my data in such a way that others could understand them with almost no inference.</td>
</tr>
</tbody>
</table>

### CONSTRUCTING MEANING

**How well do I consider and explain science content and inquiry processes, and demonstrates scientific habits of mind through reflection and reasoning?**

<table>
<thead>
<tr>
<th>No EVIDENCE</th>
<th>DEVELOPING</th>
<th>PROFICIENT</th>
<th>EXEMPLARY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depth and quality of Answer</td>
<td>There is little or no evidence of:</td>
<td>1. I state the answer to my question or hypothesis.</td>
<td>1. I discuss the answer to my question or hypothesis in a clear and general way.</td>
</tr>
<tr>
<td>Use of evidence to support and explain results</td>
<td>1. An answer to my question or hypothesis</td>
<td>2. I use observations or data incorrectly or in a general way to explain my results.</td>
<td>2. I correctly refer to certain, specific observations or data to explain my results.</td>
</tr>
<tr>
<td>Quality of connections between personal understandings, the present data, and the science content</td>
<td>2. Cited observations or data used to support my results</td>
<td>3. I state a connection between my answer and the science content, but it is unclear or essentially incorrect.</td>
<td>3. I discuss a connection between my answer and the science content that is essentially correct. I tie these ideas together with my personal understandings.</td>
</tr>
<tr>
<td>Reasoning behind sources of error and suggestions for a better experimental design</td>
<td>3. Connections between my past and present science ideas related to this content</td>
<td>4. I discuss a problem or two with the procedures of the design but do not speculate about why they occurred.</td>
<td>4. I describe sources of error in the procedures of the design and discuss the reasons why they occurred.</td>
</tr>
<tr>
<td>Focus for continued inquiry</td>
<td>4. Consideration of sources of error in my experimental design</td>
<td>5. I ask a new question or form a hypothesis that isn’t related to the science content in this inquiry.</td>
<td>5. I ask a new question or form a hypothesis about science ideas related to this science content.</td>
</tr>
<tr>
<td></td>
<td>5. Direction for continued inquiry</td>
<td></td>
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</tr>
<tr>
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</tr>
</tbody>
</table>
Appendix G Semi-Structured Interview Protocol

1. How would you describe your experience with Catlab?
2. Do you believe you learned genetics in the process? How?
3. How would you compare your genetics knowledge before and after the module?
4. Do you think your experience with Catlab was valuable? What did you value about it?
5. Was Catlab unit inquiry based? Why?
6. What is scientific inquiry? How would you define it?
7. In general, how comfortable are you when working on ill-structured problems?
8. What were your strategies when you were working on your inquiry project?
9. How did you deal with alternative hypotheses?
10. Were you comfortable in classroom environment? How would you describe interactions with your peers and instructor?
11. Did environment help you to progress in your inquiry? How?
12. What do you think about first preliminary presentations we had in the middle of the unit? Was it beneficial in any way? Did you learn anything about genetics and/or nature of scientific inquiry?
13. What about the final presentations?
14. How do you describe my role as an instructor during the unit?
15. When your predictions were not working, not agreeing with your data, how did you deal with?
16. Did you learn anything about scientific inquiry as a result of your experience with Catlab?
17. What it takes to be good in inquiry?
18. How many times did you change your model in the process of inquiry?
19. Did your opinion about nature of science change as a result of this experience? How? Why?
20. Did engaging in inquiry as a learner changed your opinions about how would you engage your own students in inquiry? Could you anticipate some of the problems?
21. Would you use the Catlab if you ever have to teach Mendelian genetics in the future? Why?
22. Relationship between evidence and claim is obviously very important in scientific inquiry. Can you tell me, how did you handle your data during your investigation to build this relationship?
23. What makes science different from other disciplines of inquiry, such as religion or philosophy?
24. What is a scientific fact?
25. Scientists agree that about 65 millions of years ago the dinosaurs became extinct. However, scientists disagree about what had caused this extinction. Why do you think they disagree even though they all have the same information?
26. A person interested in birds looked at hundreds of different types of birds who eat different types of food. He noticed that birds that eat similar types of food, tended to have similar shaped beaks. For example, birds that eat hard shelled nuts have short, strong beaks, and birds that eat insects from tide pools have long, slim
beaks. He concluded that there is a relationship between beak shape and the type of food birds eat.

a) Do you consider this person’s investigation to be scientific? Please explain why or why not.

b) Do you consider this person's investigation to be an experiment? Please explain why or why not.

27. The Manx trait in cats is believed to be an example of a lethal allele. A student set-up experiments with the Catlab software to test this hypothesis. When she mated a Manx cat with a tailed cat the program generated both Manx and tailed offspring in a 1:1 ratio. The student then selected two of these offspring as parents, a male Manx offspring, and a female tailed offspring. When she interbred these offspring she generated 89 Manx kittens and 111 tailed kittens. She rejected the hypothesis that the Manx allele was lethal because she did not get the 2:1 ratio she was expecting. Explain the error the student made in analysis of the final progeny. Outline a simple experiment which would be a better test of the hypothesis that the Manx trait is lethal.
Appendix H

Node Listing

Number of Nodes: 95
Free Nodes:
1 Collaborate
2 Collect data
3 Correct
4 Develop hypothesis
5 Experimenting
6 Funding
7 Incorrect
8 Job requirement
9 Making calculations
10 Observe
11 Personal interests
12 Run simulations
13 Scientist's background
14 Society
Trees:
15 (1) /Value of the module
16 (1 1) /Value of the module/Community of learners
Description:
Evidence of communication and collaboration between and within groups
17 (1 1 1) /Value of the module/Community of learners/Brain Storming
18 (1 1 2) /Value of the module/Community of learners/Competition
19 (1 1 3) /Value of the module/Community of learners/Peer interaction
Description:
Evidence of interaction with peers and discussion of how to evaluate the data
20 (1 1 4) /Value of the module/Community of learners/Peer review
21 (1 2) /Value of the module/Constructing explanations for observations
22 (1 3) /Value of the module/Curiosity
Description:
Asking further questions about observed data
23 (1 4) /Value of the module/Critical thinking
24 (1 5) /Value of the module/Example of inquiry based teaching
25 (1 6) /Value of the module/Generating Ideas
Description:
Evidence of generating relationships between 2 or more variables based on information gathered.
26 (1 7) /Value of the module/Inquiry based module
27 (1 9) /Value of the module/Past inquiry experiences
28 (1 10) /Value of the module/Rewarding experience
29 (1 11) /Value of the module/Simulation
Description:
Evidence of making a direct reference to the simulation
30  (1 12) /Value of the module/Student centered teaching
31  (2) /Understanding of genetics
32  (2 1) /Understanding of genetics/Valid inference
33  (2 2) /Understanding of genetics/Explanations
Description:
Evidence of explanations or conceptual models (Causal or mechanistic explanations-why or because, reflection, evaluation, or problem-solving)
34  (2 3) /Understanding of genetics/Invalid inference
35  (2 4) /Understanding of genetics/Innovation
36  (2 5) /Understanding of genetics/Compare
Description:
Evidence of making a comparison between data
37  (2 6) /Understanding of genetics/Analogy
Description:
Evidence of using an analogy (key words: like, as if)
38  (2 7) /Understanding of genetics/Content
Description:
Student gives field specific information in any form
39  (3) /Role of the teacher
40  (3 2) /Role of the teacher/Facilitator
41  (3 3) /Role of the teacher/Guidance
42  (3 4) /Role of the teacher/Student centered teaching
43  (3 5) /Role of the teacher/Teacher centered teaching
44  (3 6) /Role of the teacher/Teaching Philosophy
45  (4) /Understanding of scientific inquiry
46  (4 1) /Understanding of scientific inquiry/Bias
47  (4 3) /Understanding of scientific inquiry/Data
Description:
Talking about data gathering or using data
48  (4 4) /Understanding of scientific inquiry/Evidence
49  (4 5) /Understanding of scientific inquiry/Experiment
Description:
What is an experiment?
What does experiment involves?
50  (4 6) /Understanding of scientific inquiry/Experimental Design
Description:
Evidence of designing a new test or considering methods of testing
51  (4 7) /Understanding of scientific inquiry/features of inquiry
52  (4 8) /Understanding of scientific inquiry/Interpretation
53  (4 9) /Understanding of scientific inquiry/Modify
Description:
Evidence of changing the original relationship
54  (4 10) /Understanding of scientific inquiry/Nature of Science
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55 (4 11) /Understanding of scientific inquiry/Observation and Evidence
Description:
Scientists rationally and regularly discount anomalous data

56 (4 12) /Understanding of scientific inquiry/Prior knowledge
57 (4 13) /Understanding of scientific inquiry/resistance to change
conceptions

58 (4 14) /Understanding of scientific inquiry/Science
59 (4 15) /Understanding of scientific inquiry/Scientific fact
60 (4 16) /Understanding of scientific inquiry/Scientific method
61 (4 17) /Understanding of scientific inquiry/Social construction of
knowledge
Description:
Scientists construct knowledge in collaborative groups.
Scientists build on previous research by many scientists.
Institutional norms are established through expert review processes and exemplary
models of research

62 (4 18) /Understanding of scientific inquiry/Theory-data coordination
Description:
Scientists coordinate theoretical models with multiple sets of complex, partially
conflicting data.
Scientists seek global consistency.

63 (4 19) /Understanding of scientific inquiry/Theory-laden-ness of methods
Description:

64 (4 20) /Understanding of scientific inquiry/Worldview
65 (5) /Scientific inquiry process skills
66 (5 1) /Scientific inquiry process skills/absence of critical thinking
67 (5 2) /Scientific inquiry process skills/alternative hypothesis
68 (5 3) /Scientific inquiry process skills/Analogy
Description:
Evidence of using an analogy (key words: like, as if)

69 (5 4) /Scientific inquiry process skills/Compare
Description:
Evidence of making a comparison between data

70 (5 5) /Scientific inquiry process skills/Conceptual consistency
Description:
Evidence of evaluating the consistency of the theory across models

71 (5 6) /Scientific inquiry process skills/Confirming information
Description:
Evidence of students encountering information that confirms what they already know

72 (5 7) /Scientific inquiry process skills/Critical thinking
73 (5 8) /Scientific inquiry process skills/Data Analysis
74 (5 9) /Scientific inquiry process skills/Discrepant Information
Description:
Evidence of students encountering anomalous information in reference to what they already know

75 (5 10) /Scientific inquiry process skills/Empirical consistency
Description:
Evidence of evaluating quantitative or qualitative relationships

76 (5 11) /Scientific inquiry process skills/Extreme case
Description:
Evidence of the examination of an extreme case that may or may not be relative to a series of cases

77 (5 12) /Scientific inquiry process skills/Logical consistency
Description:
Evidence of evaluating the consistency of the rule (if, then) under different hypothetical conditions

78 (5 13) /Scientific inquiry process skills/Prediction
Description:
Evidence of expectation with regards to a relationship between or among variables

79 (5 14) /Scientific inquiry process skills/revising hypothesis
80 (5 15) /Scientific inquiry process skills/Selecting variables
Description:
Scientists select and even invent variables to investigate.

81 (5 16) /Scientific inquiry process skills/Testing hypothesis
82 (5 17) /Scientific inquiry process skills/Variables
Description:
Evidence of selecting defining or controlling variables in an effort to compile more information

83 (6) /Inquiry based teaching
84 (6 2) /Inquiry based teaching/Confused
85 (6 6) /Inquiry based teaching/interest
86 (6 7) /Inquiry based teaching/Attitudes towards inquiry
87 (6 7 1) /Inquiry based teaching/Attitudes towards inquiry/curiosity
Description:
Asking further questions about observed data

88 (6 7 2) /Inquiry based teaching/Attitudes towards inquiry/Difficulties to implement inquiry based teaching
89 (6 7 4) /Inquiry based teaching/Attitudes towards inquiry/Frustration
90 (6 7 5) /Inquiry based teaching/Attitudes towards inquiry/Negative feelings for inquiry
91 (6 7 6) /Inquiry based teaching/Attitudes towards inquiry/Positive attitude towards inquiry
92 (6 8) /Inquiry based teaching/Loss of confidence
93 (6 10) /Inquiry based teaching/Need for Authority
94 (6 11) /Inquiry based teaching/Prior knowledge
95 (6 14) /Inquiry based teaching/Student Initiation
Description:
Evidence of struggle to achieve an understanding
VITA

MUSTAFA ÇAKIR

**Place of Birth:** Antakya, TURKEY
**Date of Birth:** January 1, 1977

**Education:**
- The Pennsylvania State University, University Park, Pennsylvania
  - Ph.D. Candidate in Science Education, Curriculum & Instruction.
  - Comprehensive exam passed on: April, 15th, 2002.
- The Pennsylvania State University, University Park, Pennsylvania
  - Master of Science, Educational Psychology, December 2001
- The Pennsylvania State University, University Park, Pennsylvania
  - Master of Science, Science Education, August 2000
- Gazi University, Ankara, Turkey
  - Bachelor of Science, Biology Education, June 1997

**Professional Activities/Services**
- Proposal Reader – NARST, 2000; Strand 1, Learning: Students’ Conceptions and Conceptual Change.

**Selected Conference Presentations**

**Membership in Professional Organization**
- National Association for Research in Science Teaching
- American Educational Research Association
- Association for the Education of Teachers of Science