INSTRUCTIONAL DESIGN FOR INQUIRY SCIENCE TEACHING

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Abstract
Teaching science as inquiry is a very complex activity by nature: teachers have difficulties implementing inquiry into their teaching repertoire for various reasons. This paper describes an effort to combine research and design in the creation of a collaborative learning environment. Instructional design was aimed at providing conditions for collaborative inquiry. Intertwining design and research is particularly important for establishing collaborative context and cultural structure that support collaboration. This module was designed to engage prospective science teachers as learners in an exemplary inquiry based module for developing knowledge and skills addressed in teaching standards. It is assumed that in order to develop understanding of scientific inquiry as well as inquiry skills, participants 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. The module offered an opportunity to focus on scientific inquiry and genetics, through hypothesis testing, modeling activities, and technology use in the classroom.
The twelve participants in the study were all prospective secondary science teachers, majoring in different science disciplines. Following questions guided the study: (a) What were the prospective teachers' perceptions of inquiry as a learner? (b) What were the prospective teachers' views of using inquiry in their own classrooms and of the role of the teacher? The instructional module engaged prospective teachers in an inquiry activity in which they were asked to explore inheritance patterns in cats that required testing hypotheses and making predictions.
In order to probe participants' understandings and perspectives about scientific inquiry, we administered the Views of Scientific Inquiry (VOSI) questionnaire at the beginning of the course and at the end of the module. To further probe the prospective teachers' understandings about scientific inquiry and Mendelian genetics semi-structured interviews were conducted at the end of the module. The in-depth interviews were conducted, to also elicit views of the role of the instructor and their intentions to teach about inquiry. Finally, the final project reports were collected as secondary data sources. The findings of this study will be organized around the two research questions. The interview analysis revealed that participants claimed to have had the following experiences during the module: 1) developing critical thinking, 2) developing inquiry skills, 3) being frustrated in the process, 4) valuing the lack of immediate answers, 5) losing self-confidence, 6) questioning their experimental design 7) valuing the peer discussions and learning from peers. Both positive and negative feelings about inquiry were expressed during the interviews; attitudes towards inquiry were mostly associated with past learning experiences, general personality, and lack of inquiry experiences.
Participants were pleased with the classroom atmosphere and often talked about how it was very helpful to collaborate with peers. The value of peer interaction and collaboration was cited by all interviewees. A majority of the 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 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 to have (a) debate about their conceptual knowledge (b) subject their consensual positions to testing (c) and reach a consensus and draw conclusions.
Keywords: Teaching science as inquiry, science process skills

Introduction

The National Science Education Standards (NSES) articulate a vision of a teacher who acts as a critical decision maker, intervenes in the learning process at appropriate times in an effort to encourage, challenge, and focuses students (NRC, 1996, p. 36). Although, research produces a "pattern for general support for inquiry-based teaching" (Bransford, Brown, & Cocking, 2000; Haury, 1993; NRC, 2000, p. 126). Von Secker and Lissitz (1999) noted that little research was available describing the occurrence of NSES research based teaching strategies being utilized in science classrooms, Teacher-centered instruction and text-based learning were still "typical" throughout the 1990s (p. 1111). Numerous reports indicated that reform projects failed to yield desired outcomes in K-12 education. This failure may have been due, in part, to the fact that K-12 teachers were not adequately prepared to implement new programs and materials. With inquiry forms of teaching situated at the center of recommendations for professional practice in science education, some 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 is taught (Brickhouse, 1990). It has also been shown that designing methods courses centered around an explicit emphasis on the scientific inquiry and nature of science helps preservice 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 or been in an inquiry based science classrooms (Boardman & Zembal-Saul, 2000).

Teaching science as inquiry is a very complex activity by nature: teachers have difficulties implementing inquiry into their teaching repertoire for various reasons. Teachers who want to use inquiry learning are faced with a number of questions about identifying instructional materials that support inquiry. Certain proven strategies make inquiry learning manageable and fruitful. Researchers have found that inquiry-based science teaching is resistant to analysis, and the development and application of teaching science as inquiry remains problematic (Germann, Aram, & Burke, 1996).

One of the challenges of 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 paper describes our efforts to combine research and design in the creation of a collaborative learning environment. Our instructional design was aimed at providing conditions for collaborative inquiry and learning Mendelian genetics by implementing a computer simulation into the curriculum. Intertwining design and research is particularly important for establishing collaborative context and cultural structure that support collaboration. We argue that structuring scientific inquiry as investigation to develop explanations presents meaningful context for the enhancement of inquiry process skills and understanding of the science content.

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. This module was designed to engage prospective science teachers as learners in an exemplary inquiry based module for developing knowledge and skills addressed in teaching standards such as; teachers of science plan an inquiry-based science program for their students, teachers of science guide and facilitate learning science, teachers of science design and manage learning environments that provide students with the time, space, and resources needed for learning science, 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 (National Research Council, 1996).

Social Constructivist Views of Learning

Consistent with current science education standards (NRC, 1996) and theories of cognition, our 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 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). It is assumed that in order to develop understanding of scientific inquiry as well as inquiry skills, participants 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 are expected not only to develop an understanding of scientific inquiry and concepts, but to 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).

There is a distinction between a knowledge base of concepts, the theoretical core of science, and scientific inquiry skills. Lawson (1994) argued that inquiry skills have a separate knowledge base related to evidence. Moreover, cognitive psychologists have also distinguished various forms of science learning; including learning science concepts, learning *about* science, and learning how *to do* science (Hodson, 1993; Kuhn, Amsel, & O'Loughlin, 1988). From a constructivist view of learning, inquiry-based project work provides good opportunities for individual knowledge construction. Through collaboration, groups of students can learn how to use negotiation of meaning and reaching consensus as important tools to cope with discrepancies and disagreement.

Implementing Technology into Science Classroom

Reform documents advise teachers to utilize inquiry based, student centered instruction that will facilitate students' construction of knowledge: The use of learning technologies to support students in a deeper understanding of a specific subject-matter is encouraged. 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." (p. 2002). Some studies concluded that computer-assisted instruction was effective in improving students' science achievement and problem solving skills both in high school and undergraduate levels (Ferguson & Chapman, 1993; Levine, 1994).

One kind of learning technologies are computer simulations, they can be used to improve the teaching of scientific processes along with the 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). Computer simulations encourage the use of "what if" questions and support students to think hypothetically and test their hypothesis by identifying and controlling variables (Lin & Lehman, 1999). Stratford (1997) and Windschitl & Andre (1998) have reported that learning technologies designed within coherent instructional contexts can lead to improved science concept learning. However, there is still a need for connection of such conceptual learning with development of a broad range of scientific inquiry skills.

Computer Simulation to Support Learning about Scientific Inquiry

Mendelian Genetics Computer Simulation, CATLAB, is a software program that allows students to generate various characteristics in cats and explore the inheritance of those characteristics (Kinnear, 1998). CATLAB is based upon a valid scientific model of a genetic population. The simulation is used as a medium that has the potential to involve learners actively in science inquiry and in the learning of 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), 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) (see Figure 1.)

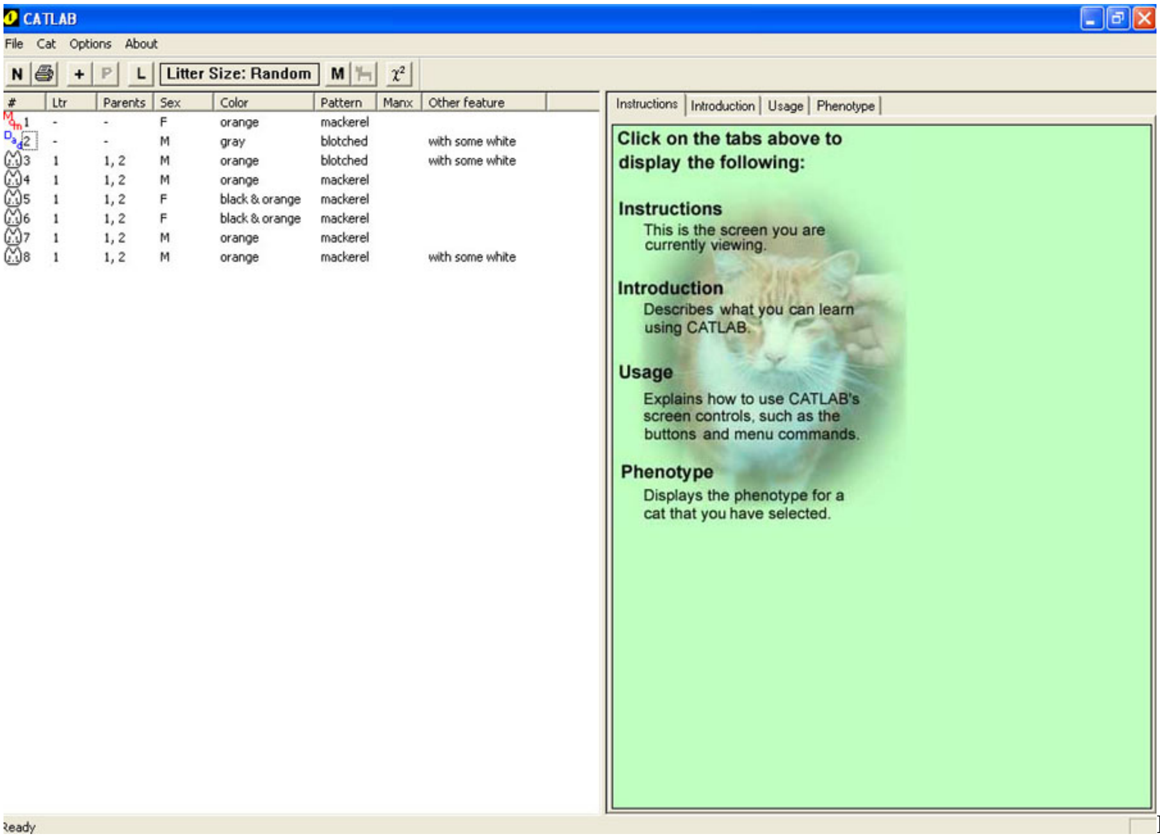

Figure 1: Screenshot of Catlab simulation

The Nature of the Course

The module was situated in a teaching and learning course, Technology Tools for Supporting Scientific Inquiry (TTSI), focused on inquiry and technology for prospective secondary science teachers. TTSI is the first course in a three-course sequence required of all secondary science education majors. The TTSI course is a 3-credit course and met a total of 3 hours per week. The major goal of the course is to help prospective science teachers develop an understanding of scientific inquiry, while developing skills in using learning technologies. The intent of the course was to create an innovative environment for teaching and learning scientific inquiry as science content, in alignment with recommendations of the NSES.

The Nature of the Instructional Module

The CATLAB module offered an opportunity to focus on scientific inquiry and genetics, through hypothesis testing, modeling activities, and technology use in the classroom. In designing the genetics inquiry instructional module, we planned to engage prospective teachers in an inquiry activity in which they were asked to explore inheritance patterns in cats that required hypothesis testing and making predictions. We utilized a collaborative inquiry approach was to create the teaching and learning environment. Collaborative inquiry involves cognitive interactions between both teacher and students, and students with each other. While it could be argued that the content of CATLAB is more relevant to prospective biology teachers, processes and problem solving skills of inquiry are important for students of all science disciplines.

Lessons in the Genetics Inquiry Module

Session 1- Review of genetics and introduction to CATLAB

After an initial survey of Mendelian genetics knowledge, four participants who were biology education majors volunteered to conduct a review of Mendelian genetics concepts for their peers. The major concepts they reviewed were: Mendel's laws of heredity; monohybrid – Dihybrid crosses, dominance, recessive ness, and allele, homozygous, heterozygous; multiple -alleles, incomplete dominance; and sex-linked inheritance. After this review of Mendelian genetics concepts, the instructor demonstrated how to use Catlab to test hypotheses. Following the demonstration participants worked in pairs on example problems.

Session 2- Hypothesis testing using CATLAB

The instructor used a structured inquiry approach to teach the whole class about hypothesis testing. The instructor used both Mono and Dihybrid cross scenarios as examples, showing participants how to test a hypothesis in each situation. Participants tested another hypothesis, on their own, using Catlab. A class discussion followed, which focused on issues, such as making assumptions, predictions, collecting data, evidence, experimental design, controlling variables and testing hypotheses. Mono and Dihybrid crosses were reviewed during this discussion, and participants reconnected the discussion to the Punnet squares that would result from the selected crosses. Participants were given four examples of problem scenarios and asked to choose one for their inquiry project. They also had the option of coming up with their own question to solve.

Session 3- Beginning to work on inquiry projects

In the third session, the six pairs of prospective teachers started to work on their inquiry projects at separate work stations; all pairs selected their driving questions from the list they were given. Since there were total of four driving questions and six pairs of participants, two driving questions were investigated by two different pairs.

Table 1: Sequence of class sessions and activities

Session number (Date)	Description of activities complementing the inquiry project
1 (2/13/2003)	• Introduction to Mendelian Genetics: Major concepts and operations were presented by the volunteer students who majored in biology; followed by class discussions of exercise problems which were provided by the instructor • Introduction to Catlab: The instructor demonstrated how to use the computer simulation
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 of the activity and evaluation of the proposed solutions
3 (2/20/2003)	• Student pairs worked on their inquiry projects • Discussion of probability, Mono and Dihybrid crosses
4 (2/25/2003)	• Preliminary project presentations to peers • Continuing to work on inquiry projects
5 (2/27/2003)	• Continuing to work on inquiry projects • Class discussion of observation vs. inference and assumption vs. evidence to scaffold participants' understandings
6 (3/4/2003)	• Continuing to work on inquiry projects • Discussion of building and testing hypotheses and the role of models in science
7 (3/6/2003)	• Final inquiry project presentations

Participants were asked to gather data using 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. Classroom activities and interactions focused on generating ideas, gathering data, and critiquing results and conclusions (Table 2). Numerous participants thought they had answered their driving question by the end of the third session. Since some of the pairs announced they had completed their inquiries, we consulted the other groups, and decided to have preliminary presentations in the next class session.

Session 4- Preliminary presentations of pair projects

In the beginning of the fourth session, pairs presented their findings and initial arguments. , Multiple relationships were generated by the pairs and were presented to the whole class. Although the 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, the 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 these preliminary presentations, participants went back to their work stations and continued their inquiry project. During this work time they evaluated the new information and insights gained from their peers. Some participants tried to disprove their peers' claims to make their own claims more plausible.

Table 2: Relationship of components of inquiry to CATLAB

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

Session 5- Class discussion of observation vs. inference

Participants collaborated between and within groups, as well as with the instructor. Sometimes they used someone else's expertise to come up with an explanation for their data. The instructor led a discussion of observation versus inference and assumptions versus evidence.

Session 6- Building and revising models of inheritance

As they progressed with their investigation, the prospective teachers tried to build a valid model for coat color and pattern inheritance in cats. The pairs constantly revised their models, as they continued testing new hypotheses.

Session 7- Final inquiry presentations to the class

During the seventh and final class session of the module, the prospective science teachers shared their investigations with their peers via computer projection. In order to provide each pair with enough time to present their findings and to have discussions and criticism, presentations were done in two separate rooms. Each group presented their findings and proposed inheritance models, highlighting its 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 author as an 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 in groups, social negotiation, and explanation-building. The instructional goals of the module were to develop the students' conceptions of Mendelian genetics and scientific inquiry; the activity itself involved students in collaborative inquiry and experimentation using computer simulation.

Methodology

Participants: The twelve participants in the study were all prospective secondary science teachers, majoring in different science disciplines. Of the twelve prospective science teachers, four were preparing to teach biology, six Earth and Space science, one physics, and one chemistry.

Research questions**:** Due to the complexity of studying the classroom interactions of this preservice teacher classroom, we crafted the following research questions

(1) What were the prospective teachers' perceptions of inquiry as a learner?

(2) What were the prospective teachers' understandings of inquiry and Mendelian genetics following the module?

(3) What were the prospective teachers' views of using inquiry in their own classrooms and of the role of the teacher?

We designed the instructional module and used qualitative research methodology to answer the research questions. The instructional module engaged prospective teachers in an inquiry activity in which they were asked to explore inheritance patterns in cats that required testing hypotheses and making predictions.

Data sources

In order to probe participants' understandings and perspectives about scientific inquiry, we administered the Views of Scientific Inquiry (VOSI) questionnaire at the beginning of the course and at the end of the module. VOSI was developed and validated by Schwartz, Lederman, & Thompson (2001). Data collected through the VOSI and follow-up interviews provided confirmatory evidence for teachers' initial views of inquiry, and also of their developing

understandings. To evaluate prospective teachers' understandings of Mendelian genetics concepts, we administered pre/post instructional tests, adapted from Simmons & Lunetta (1993).
To further probe the prospective teachers' understandings about scientific inquiry and Mendelian genetics the author conducted semi-structured interviews at the end of the module. The in-depth interviews were conducted, to also elicit views of the role of the instructor and their intentions to teach about inquiry. Finally, the final project reports were collected as secondary data sources.
In summary, data sources included: a) pre and post-instruction questionnaires; b) semi-structured interviews c) inquiry project reports and presentations.

Findings and Discussion

The findings of this study will be organized around the three main research questions.
What were the prospective teachers' perceptions of inquiry as a learner?
The interview analysis revealed that participants claimed to have had the following experiences during the module: 1) developing critical thinking, 2) developing inquiry skills, 3) being frustrated in the process, 4) valuing the lack of immediate answers, 5) losing self-confidence, 6) questioning their experimental design 7) valuing the peer discussions and learning from peers.
Mary expressed her preferences as a learner for direct instruction:
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. (Post-interview).
What were the prospective teachers' understandings of inquiry and Mendelian genetics following the module?
Understanding of scientific inquiry: Analysis of VOSI revealed prospective science teachers developed more informed views about scientific inquiry overall. Although scientific inquiry and nature of science are separate constructs they overlap and interact in many ways. Pre and post VOSI analysis showed that participants developed better understandings of multiple methods and purposes of scientific investigations; importance of consistency between evidence and conclusions; distinction between data and evidence; recognition of assumptions involved in formulating and conducting scientific inquiry, the role of communication in the development and acceptance of scientific knowledge. The most emphasized points were the social aspects of science, peer review, and worldview of scientists. For example;

Even if they follow the same procedures to collect data, they will still have personal biases that will affect the outcome;

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;

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.

Understandings of Mendelian Genetics: Mendelian genetics pre and posttest items intended to measure propositions in three domains, namely gamete combination (GC), transmission of inheritance (I) and probability (P). Some items fall into more than one domain, Table 4 shows item numbers and their corresponding propositions.

Table 3: Genetics test items' corresponding domains of propositions

<u>Item #</u>	1	2	3	4	5	6	7	8	9
<u>Proposition</u>	GC	GC P I	GC P	GC P	*	GC P I	GC P	GC I	GC I
<u>Item #</u>	10	11	12	13	14	15	16	17	18
<u>Proposition</u>	*	GC	GC P	GC P	GC I	GC P I	GC I	GC I	*

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.

Genetics pretest revealed that most of the participants, even biology majors, did not have strong conceptual understanding of Mendelian genetics and they had very mechanistic understanding of gamete combination and probability at the beginning of the module, posttest results showed considerable improvement given the short time span and the focus of the module, see Figure 1 for summary and comparison. We did not try to teach genetics directly. That was a secondary benefit of the inquiry-oriented module. Tests include propositions from three domains, namely gamete combination, transition of inheritance, and probability, see Table 3. Probability concept seemed the most difficult one for them to grapple with. They also had some difficult time learning the basic jargon of Mendelian genetics. Interestingly, almost all of them knew how to make and use Punnet square; however the conceptual knowledge and cognitive operations behind the Punnet square was mostly absent. Most of them used punnet square without conceptual understanding of it; even after the module. When they presented with the same problem in a different way they fail to answer. One of the most confused concepts was allele; they frequently used allele and gene concepts instead of one another. They showed some expertise in testing hypothesis after the module. Every one of the pairs came up with well substantiated answers to their driving inquiry questions. In fact, at the end of the final presentations they were able to identify a total of seven genes and their interaction to one another; (participants did not know how many sets of genes were Catlab included). Basically they identified the inheritance model that the Catlab program was built on.

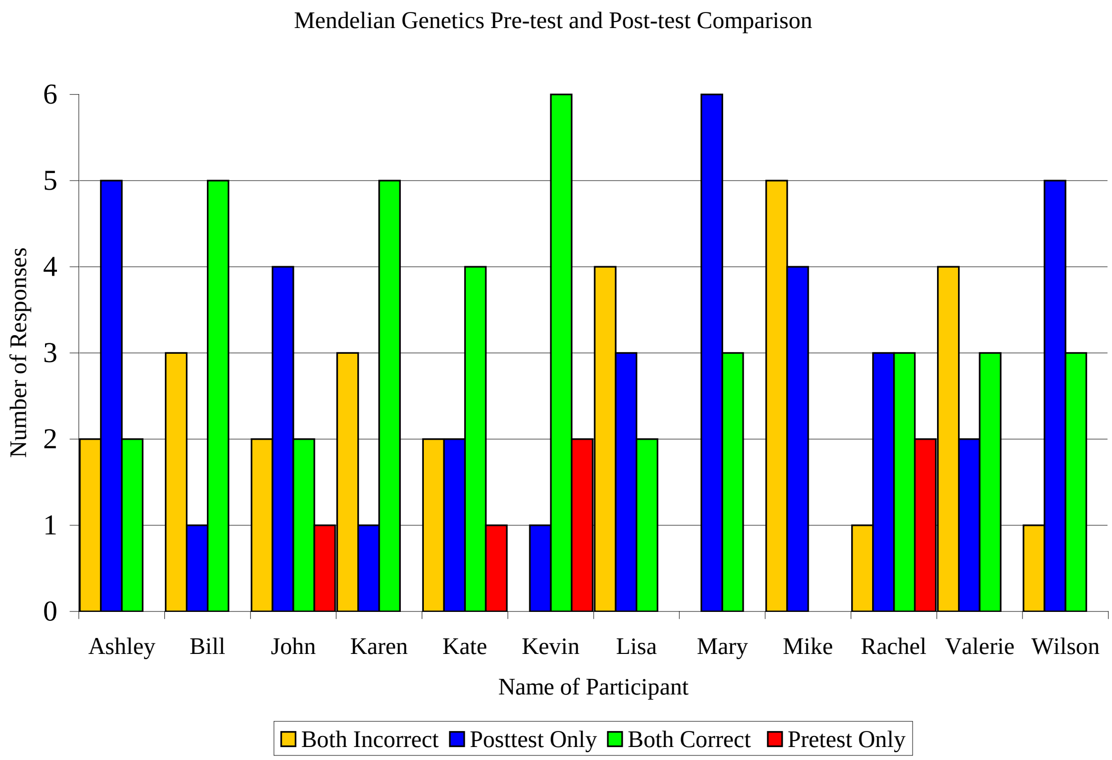

Figure 1: Mendelian genetics pre and post-test comparison

What were the prospective teachers' views of using inquiry in their own classrooms and of the role of the teacher?

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 (post interview)

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.

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". 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.

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
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.
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.

While Lisa 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.

Lisa's views of using inquiry apparently stemmed from her own experiences in high school 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.

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.

When they were asked about the module students stated:

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

And about the module he continued:

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

About Catlab as an inquiry based instructional tool: Prospective science teachers' views about Catlab were highly positive, for example, Brian stated:

It was very fun, we really got into it, and we learned a lot" and also "I think it was very enjoyable scientific modeling program, it really did worked well, easy to use and informative I liked the program.

Karen had mixed emotions about it saying:

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 a lot of instantaneous reward or reinforcement, so I think it was definitely good.

They enjoyed the program as it related to their lives since many of them have cats at home, an excerpt from Mary's interview **"I can explain my cat, it was very exciting**". Lisa, prospective biology teacher, on Catlab:

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 a scientific problem and explore it.

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.

Attitudes towards inquiry: Both positive and negative feelings about inquiry were expressed during the interviews; attitudes towards inquiry were mostly associated with past learning experiences, general personality, and lack of inquiry experiences. Bill and Kevin, majored in Earth and Space science, as a pair were very successful with 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 hypothesis, in interview when Bill was asked when they finished their project he 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 move on to Manx trait and the albino traits, those were the two we never get around to investigate if we had another day I am sure we would solve those too.

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.

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

Although she believed in inquiry teaching, Karen wanted to add that:

I like to have answers immediately. That's just my personality, 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.

Creating Community of Learners:

Participants were pleased with the classroom atmosphere and often talked about how it was very helpful to collaborate with peers. For example when she was asked about the preliminary presentations Karen said:

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.

The value of peer interaction and collaboration was cited by all interviewees, Rachel expressed similar opinion:

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

Experiencing inquiry in such environment also had 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 form having a hypothesis that's wrong than having one that the data supported.

A majority of the 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 from one interview documents 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.

Implications for Science Teacher Education

Although the research base is growing on science classroom discourse, still little is known on hypothesis testing, explanation-building processes in student-centered small-group learning environments. While there were a number of variables including the nature of participants, the classroom setting, participants other course experiences, and the computer software that may have influenced the improvements in understandings and process skills, one of the contributing factors to gains may have also been our instructional approach.

Socially constructed processes like negotiation, consensus, and collaboration with peers and instructor played very important role in directing cognition and triggering individual reflection. Guidance from peers who had more expertise and instructor 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. Our research provided evidence that hypothesis testing can support the integrated acquisition of conceptual and procedural knowledge in science. However, 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.

Our study suggests that 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 claim of a lack of inquiry based experiences in science teacher education.

The results in this investigation suggest that, most of the prospective science teachers lack a sound background as 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 were 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 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 learners' ability and understanding level. Another explanation for this situation is, instead of attributing poor performance to cognitive deficiencies, taking Lave & Wenger's (1991) and Brown & Campione's (1996) advice and 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. In the beginning prospective biology teachers considered themselves as experts not only they did not pay attention to their peers findings but also they failed to test, using Catlab, some of their early predictions, instead jumping to a conclusion and making claims with no supporting evidence. Therefore when they were presented with so 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 to have (a) debate about their conceptual knowledge (b) subject their consensual positions to testing (c) and 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.

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 about scientific inquiry via inquiry-based teaching is very important since it provides an environment for them to develop the ability to teach in a manner consistent with the vision of the standards.

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 helped us to engage our prospective teachers in science as inquiry. Our technological tool 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.

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References

American Association for the Advancement of Science. (1990). Science for all americans. New York: Oxford University Press.

American Association for the Advancement of Science. (1993). Benchmarks for science literacy. New York: Oxford University Press.

Bell, R., Lederman, N., & Abd-El-Khalick, F. (1998). Preservice teachers' beliefs and practices regarding the teaching of the nature of science. Paper presented at the Annual Meeting of the National Association for Research in Science Teaching, San Diego, CA.

Boardman, L., & Zembal-Saul, C. (2000). Exploring prospective elementary teachers' conceptions of scientific inquiry. Paper presented at the Annual Meeting of the National Association for Research in Science Teaching, New Orleans, LA.

Borko, H., & Putnam, R. T. (1995). Expanding a teacher's knowledge base: A cognitive perspective on professional development. In T. Guskey & M. Huberman (Eds.), Professional development in education: New paradigms and practices (pp. 35-65). New York: Teachers College Press.

Bransford, J. D., Brown, A. L., & Cocking, R. R. (2000). How people pearn: Brain, mind, experience, and school. Washington, DC: National Academy Press.

Brickhouse, N. W. (1990). Teachers' beliefs about the nature of science and their relationship to classroom practice. Journal of Teacher Education, 41(3), 53-62.
Brown, A. L. (1992). Design experiments: Theoretical and methodological challenges in creating complex interventions in classroom settings. Journal of the Learning Sciences, 2(2), 141-178.
Brown, A. L., & Campione, J. C. (1996). Guided discovery in a community of learners. In K. McGilly (Ed.), Classroom lessons: Integrating cognitive theory and classroom practice (pp. 229-270). Cambridge, MA: MIT Press.
Ferguson, N. H., & Chapman, S. R. (1993). Computer-assisted instruction for introductory genetics. Journal of Natural Resources and Life Sciences Education, 22, 145-152.
Finley, F., Lawrenz, F., & Heller, P. (1992). A summary of research in science education-1990. Science Education, 76, 239-254.
Fisher, B. W. (1997). Computer modeling for thinking about and controlling variable. School Science Review, 79, 87-90.
Germann, P. J., Aram, R., & Burke, G. (1996). Identifying patterns and relationships among the responses of seventh-grade students to the science process skill of designing experiments. Journal of Research in Science Teaching, 33(1), 79-99.
Haury, D. L. (1993). Teaching science through inquiry: ERIC Document No. ED 359048.
Hodson, D. (1993). Re-thinking old ways: Towards a more critical approach to practical work in school science. Studies in Science Education, 22, 85-142.
Kinnear, J. (1998). Catlab (Version Third edition) [Computer Simulation]. Stuart, FL: EME Corporation.
Kuhn, D., Amsel, E., & O'Loughlin, M. (1988). The development of scientific thinking skills. San Diego: Academic Press.
Lave, J., & Wenger, E. (1991). Situated learning: Legitimate peripheral participation. New York: Cambridge University Press.
Lawson, A. E. (1994). Research on the acquistion of science knowledge: Epistemological foundations of cognition. In D. Gabel (Ed.), Handbook of research on science teaching and learning (pp. 131-176). New York: Macmillan Publishing Company.
Levine, T. (1994). A computer-based program can make a difference: The case of the rediscover science program. Studies in Educational Evaluation, 20, 283-296.
Lin, X., & Lehman, J. D. (1999). Supporting learning of variable control in a computer-based biology environment: Effects of prompting college students to reflect on their own thinking. Journal of Research in Science Teaching, 36(7), 837-858.
Mintz, R. (1993). Computerized simulation as an inquiry tool. School Science and Mathematics, 93, 76-80.
National Research Council. (1996). National science education standards. Washington, DC: National Academy Press.
National Research Council. (2000). Inquiry and the national science education standards: A guide for teaching and learning. Washington, DC: National Academy Press.
Schwartz, R., Lederman, N., & Thompson, T. (2001). Grade nine students' views of nature of science and scientific inquiry: The effects of an inquiry-enthusiast's approach to teaching science as inquiry. Paper presented at the Annual Meeting of the National Association for Research in Science Teaching, St. Louis, MO.
Simmons, P. E., & Lunetta, V. N. (1993). Problem-solving behaviors during a genetics computer simulation: Beyond the expert/novice dichotomy. Journal of Research in Science Teaching, 30(2), 153-173.
Stratford, S. J. (1997). A review of computer-based model research in precollege science classrooms. Journal of Computers in Mathematics and Science Teaching, 16(1), 3-23.
von Secker, C. E., & Lissitz, R. W. (1999). Estimating the impact of instructional practices on student achievement in science. Journal of Research in Science Teaching, 36, 1110-1126.
Vygotsky, L. S. (1978). Mind in society: the development of higher mental processes. In V. M. Cole, John-Steiner, & E. Souberman, (Ed.). Cambridge, MA: Harvard University Press.
Wenger, E. (1998). Communities of practice. Learning, meaning, and identity. Cambridge: Cambridge University Press.
Windschitl, M. (1996). Student epistemological beliefs and conceptual change activities: How do pair members affect each other? Journal of Science Education and Technology, 6, 24-38.
Windschitl, M., & Andre, T. (1998). Using computer simulations to enhance conceptual change: The roles of constructivist instruction and student epistemological beliefs. Journal of Research in Science Teaching, 35(2), 145-160.