Improving Nature of Science Understandings through Scientific Inquiry

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Abstract
The main goal of this study was to examine prospective secondary science teachers' developing understanding of nature of science (NOS) while engaging in scientific inquiry. A computer simulation of inheritance processes was used in combination with small-group discussions to enhance participants' understandings of NOS. Structuring scientific inquiry as investigation to develop explanations presents meaningful context for the enhancement of understanding of the NOS. 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 NOS, inquiry project reports, and semi-structured interviews with seven selected participants. Findings suggest that while studying important concepts in science, carefully designed inquiry experiences can help students 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, and the ways in which they construct and share their explanations. Prior to this experience the prospective teachers held uninformed views of NOS. After the module, participants demonstrated extended expertise in their understandings of following aspects of NOS: a) the iterative nature of science; b) the tentativeness of specific knowledge claims; c) the degree to which scientists rely on empirical data and broader conceptual, metaphysical commitments; d) the need for conceptual consistency; e) multiple methods of investigations and multiple interpretations of data; and f) social aspects of science.

Keywords: Nature of Science, Scientific Inquiry

Introduction

Implementing inquiry-based teaching in order to create a learning environment for students to become scientifically literate is a challenging task for science teachers. 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). 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.

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. 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.

Purpose and Research Question

The purpose of this study was exploring prospective secondary science teachers' developing understandings of nature of science as they engage in scientific inquiry. Consistent with the views expressed in the Standards, an instructional module was designed to engage prospective secondary science teachers in investigation of inheritance patterns in domestic cats, using a computer simulation. The research questions for this study was "what is the nature of prospective secondary science teachers' understandings of nature of science and in what ways do these understandings change after engagement in guided inquiry that includes constructing and testing hypotheses?"

Context and design of the study

Qualitative inquiry methods were used 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, the research design was structured within a theoretical framework of a grounded theory inquiry tradition that is applied within case study design (Creswell, 1998; Strauss & Corbin, 1998).

The context for the study was a teaching and learning course focused on inquiry and technology for prospective secondary science teachers. 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. 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). 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.

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. This protocol was decided to be most appropriate for this study because of individual differences in understandings within the case (Merriam, 1998)

Interview transcripts, pre-tests, and post-tests of views of scientific inquiry and inquiry project reports, and presentations were used as the primary source of data. Secondary supporting data consisted of homework assignments, and researcher's journal. Data were collected throughout the duration of the module, and interviews with selected participants were conducted after the instructional module.

Findings and Discussion

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.

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. In post-VOSI interviews 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.

Scientists are going to interpret data differently based on prior knowledge and/or experience (Lisa, Post-VOSI);

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

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.

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);

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

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).

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);

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);

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.

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.

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);

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);

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).

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.

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.

Representative examples include the following:

Initially, Ben defined data as: "A set of known facts" (Pre-VOSI).

Valerie's definition of data was: "Information, the numbers, measurement, and raw untouched results of an experiment or observation" (Pre-VOSI).

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

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).

The following quotes provide evidence of change:

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

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).

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).

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) and Karen stated: "Evidence is something you look for before you conduct the experiment to help you write your hypothesis" (Pre-VOSI).

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).

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

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).

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

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).

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

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.

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).
Making sense of numbers/observations finding trends, percents etc., usually it involves a lot of Excel work (Mary, pre-VOSI).

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).

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

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).

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.

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).

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

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).

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).

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).

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).
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).

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).

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).

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.

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.

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).

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

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.

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

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.

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**

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.

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.

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.

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:

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.

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:

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.

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