Modeling Aspects Of Nature Of Science To Preservice Elementary Teachers

Paul Ashcraft

School of Science, Penn State Erie, The Behrend College, Erie, PA 16563

Abstract. Nature of science was modeled using guided inquiry activities in the university classroom with elementary education majors. A physical science content course initially used an Aristotelian model where students discussed the relationship between distance from a constant radiation source and the amount of radiation received based on accepted "truths" or principles and concluded that there was an inverse relationship. The class became Galilean in nature, using the scientific method to test that hypothesis. Examining data, the class rejected their hypothesis and concluded that there is an inverse square relationship. Assignments, given before and after the hypothesis testing, show the student's misconceptions and their acceptance of scientifically acceptable conceptions. Answers on exam questions further support this conceptual change. Students spent less class time on the inverse square relationship later when examining electrostatic force, magnetic force, gravity, and planetary solar radiation because the students related this particular experience to other physical relationships.

Keywords: Nature of Science, scientific method, physics education research
PACS: 01.40.Fk, 01.40.gb, 01.40.jc

INTRODUCTION

As an instructor of a freshmen level physical science class, my students usually fell into two categories, elementary education majors and students who were taking the last science course of their lives. The scientific method and the nature of science ([1], NOS) is part of my class' curricula because pre-service teachers will be teaching both topics in their future elementary classrooms, since these topics are on the national standards and many state standards [2]. These topics are included in the standards to promote scientific literacy and to help non-scientists understand science's role in society [3]. Often times these topics were quickly covered, making sure certain points were emphasized that could be asked objectively on a future exam. A student could memorize the definition of *scientific fact*, *hypothesis*, *theory*, and *scientific law*, memorize the text's five steps of the scientific method [4] and easily answer the exam questions on those topics.

Novice and preservice teachers tend to exhibit behaviors in the classroom that can only be modeled on their past experiences as students [5, 6, 7]. My students, modeling my class in their own future classrooms, would have their students learn vocabulary words and answer questions on tests written at their students' reading level. Yet, teachers are expected to have a scientifically accepted view of NOS and teach science using an inquiry approach [1,8]. Many teachers do not have a mature view of NOS and some preservice teachers only receive explicit instruction on NOS in their science teaching methods classes [9]. However, university science faculty can model future teacher's teaching methods by explicitly teaching NOS and by using constructivist teaching methods involving students using prior knowledge acquired through personal experiences or a shared social experience [10] as a base for a better understanding of scientifically accepted concepts. This case study will examine a class that models both a passive Aristotelian classroom and guided inquiry in order to understand a physical concept.

THE CASE STUDY

The following case study describes a teaching method where the students participated in a passive, Aristotelian classroom, considering a concept that has been experienced by everyone. After discussion, a conclusion was reached using accepted "truths" or principles. Later the same concept is investigated, using constructivist methods, the scientific method and the collection of data. The data supports conclusions that are very different than expected, yet applicable to many other physical concepts. Student comprehension improved, evidenced by comparing reasons for choosing multiple-choice answers of similar questions given before and after the constructivist intervention.

Context

This study took place in a general education physical science course at a medium sized, rural, four-year Midwestern university. Forty of the 45 students enrolled in two classes participated in this study. One class of 17 was almost entirely sophomore, female, elementary education students; the other class was about one half education majors and juniors and about one quarter male and seniors.

During the first week of the semester, the class discussed the definition of a *scientific fact*, how these facts support *hypotheses*, how *theories* are a large synthesis of supported hypotheses, and finally how a *scientific law* is a theory that has not yet been refuted but may someday be proven wrong. Included in the discussion was the fact that better measuring or observing procedures can change scientific facts; for example, the Hubbell telescope radically transformed the knowledge base in astronomy. Another classroom example of the non-static nature of science was the Newtonian concept of gravitation replacing Aristotelian concepts.

Aristotelian Class

Prior to the class discussion of the inverse square law, the students answered the following problem outside of class and submitted their responses electronically:

> Choose an answer and please tell me why you chose that answer (in about 30 words). What was your thinking to come up with that answer? Why did you discount other answers?
>
> You are standing in a room that is lit by a single light bulb. You stand five feet from that light bulb. You move so you are now ten feet from that light bulb. How has the brightness of the light hitting your face changed when you moved from five feet away to ten feet away?
>
> a) you will receive four times as much light
> b) you will receive two times as much light
> c) you will receive the same amount of light
> d) you will receive one half as much light
> e) you will receive one quarter as much light *
> * Denotes correct answer

Student responses to this qualitative assignment are listed in Table 1. The participants overwhelmingly answered "D" while 8 percent correctly answered "E" and another 7 percent answered "C" because they read the question differently. ("The amount of light doesn't change; the light doesn't care where you are standing.") One student responded “C or D,” leading to 2.5 responses to “C” and 32.5 responses to “D.”

During the first inverse square law discussion, the students paired up, read their answers to their partner from the hard copy they brought to class, and discussed the problem. The two students came to a consensus, and those answers were tallied. Since the overwhelming majority chose "D", the pair’s discussion confirmed that answer, and there were no dissenters in the classroom discussion. The instructor presented reasons for all answers (from the student's emails), some of which were conflicting. The class concluded that there is an inverse relationship between distance from the source and the amount of light you receive; if you double the distance from the light, one receives half the light as before.

Although there were no dissenters during the class discussion, after the class ended, one student told me that he still thought the answer was "E," that the light received had an inverse square relationship to distance. I asked him why he didn't say anything in class; he told me that everyone was so confident that he didn't want to say anything. Thus we should not assume that just because students appear to agree with the general consensus in these types of classroom exercises, that they actually do.

Data Collection Through Modeling and Experiment

In the next class period, following the above discussion, a biologist described the methodology of his current research and gave an example of the scientific method at work. He emphasized teamwork in science, how creativity plays a large part in research, and how assumptions and hypotheses are constantly being tested. His most important research involved an experiment that produced totally different results than expected; one that he had his student replicate over and over (until the professor replicated it) because data went against current theory. He emphasized that while his research group followed certain guidelines, that there was not one and only one scientific method to add to scientific knowledge.

During the third class period we revisited the radiation and distance relationship and considered the question using the scientific method:

> We clearly stated the question: How does the amount of light received change as you

change the distance from a constant light source?

We proposed a hypothesis: The amount of light is inversely related to distance.

We considered what consequences would happen if this hypothesis was true: If you double your distance from the source, you will receive one half the light as before; if you halve the distance, you will receive twice the light. Using this logic, if you tripled your distance, you would receive one-third the light and if you quadrupled the distance, you'd receive one-quarter the light.

Students then participated in a thought experiment that considered a globe that could be lit. The students considered the following scenario: the light bulb inside the globe was a point source located at the sphere's center that emitted light equally in all directions, so the light bulb emitted radiation evenly upon the surface of the globe. In order to calculate the amount of radiation received for every square centimeter on that globe, the class calculated the surface area of that sphere and divided the total radiation emitted by that surface area.

Next, spheres of different sizes were examined. As the radius doubled, the radiation per unit area was one-fourth the original. When the radius tripled, the radiation was $1/9^{th}$ what it was before; if the distance quadrupled, the radiation reduced to $1/16^{th}$ of the original value.

The class rejected their hypothesis that the radiation was inversely related to distance from the source because the data supported a hypothesis that the radiation had an inverse square relationship to distance from the source.

In the next week, the students answered an assignment question that was literally the same as before with the exception that numerical values were given to the amount of radiation received at the two locations. The student responses were markedly different (second line, Table 1). Thirty-eight subjects responded with 79 percent now replying that one received one-quarter of the radiation when one is twice the original distance, while 13 percent still believed that you'd only receive one-half the radiation.

Later the class tested this relationship measuring gamma rays (a type of electromagnetic radiation) in three-minute intervals when the radioactive sample was different distances from the Geiger tube. The students assumed one measurement was a "true" measurement and calculated theoretical counts per minute expected at both shorter and longer distances. Differences between empirical and expected data were between -10 and 30 percent, which lead to discussions of random error, sampling error, and assumptions in measuring.

One week later two similar, but open-ended, questions (one qualitative, one quantitative) were asked of the students on their exam. The instructor translated the student responses to equivalent multiple-choice question answers. These results, listed on the third and fourth lines of Table 1, show that 88 percent responded correctly on the qualitative question and 65 percent correctly calculated the correct quantitative response using the inverse square relationship. Only 3 and 8 percent, respectively, responded that there is an inverse relationship between distance and radiation received, the common initial misconception of the class. Responses listed as "other" include two students listing answers that did not appear to be logical and six students calculating the quantitative question using a direct relationship (or using a constant ratio between distance and radiation received).

DISCUSSION

The students, by modeling aspects of NOS by working in a scientific manner, experienced the scientific method. Guided inquiry activities produced data that was then examined for trends. Once a trend was recognized, explanations for this new concept were conceptualized and data justified their new conceptualization. After explicit instruction on NOS, with explicit reflection and discussion about the processes the students engaged in, these students should then be more likely to model this teaching method in their own future classrooms. While one could argue that this experience could be recalled or even reviewed during the students' method class instruction on NOS, explicit reflection and discussion must also happen in the classroom context in order for gains to be made

TABLE 1. Number of Student Reponses to Questions Dealing with the Inverse Square Relationship between the Distance from Radiation Source and Amount of Radiation Received. Note: MC denotes multiple-choice question. OE denotes open-ended question. * denotes correct answer.

	A	B	C	D	E*	Other
Qualitative assignment (MC)	0	0	2.5	32.5	3	0
Quantitative assignment (MC)	0	2	1	5	30	0
Qualitative exam question (OE)	0	2	0	1	35	2
Quantitative exam question (OE)	2	1	0	3	26	8

in understanding NOS [11, 12].

Was the time spent searching for the answer worth the amount learned from it? The same instructor usually uses 100 minutes of normal lecture time while the new method takes slightly more time, estimated at 125 minutes. Over the semester, the class spent less time examining the (inverse square) relationship between electrostatic force and distance, between magnetic force and distance, between gravitational force and distance, and between the amount of solar radiation received and planetary distance from the Sun. Thus, although it appears that an extensive amount of time was spent on this topic, time spent on other similar topics later was minimized.

A more disturbing aspect was the time spent modeling Aristotelian behavior, along with the class recognizing and then solidifying their misunderstanding of a physical relationship. As teachers, we often feel the need to teach, to correct, and to steer a student onto the correct path of thinking. As professors, we often feel the need to profess our expertise in our chosen field. Yet, if we allow the students to express themselves and their misconceptions (and even let them write them down in their notes), the students themselves will recognize their misconceptions and change their conception of their world, resulting in longer-lasting learning [13].

In summary, while this method is more time consuming and student-centered, students performed better on exam questions about inverse square relationships after modeling scientific methods than previous classes did by listening or watching a demonstration of science. This model can be used for other content and/or other courses since the act of asking students what they believe and why they believe it, can apply to any field. While this method asks the students their preconceptions (and misconceptions) as the starting point of a learning cycle, NOS and the scientific method are modeled through guided inquiry. If the student has scientifically valid preconceptions, the modeling of the scientific method makes those correct conceptions more concrete. If there are misconceptions, one can use the scientific method to provide evidence against the misconceptions and towards another conception, and lead students to a more scientifically acceptable conception. This particular inquiry led most students to a different-than-expected answer, causing them to examine the problem closer to explain their data. This understanding of the problem and its solution is valuable later in the semester when the students encountered analogous situations.

This type of instruction has great potential for helping students develop an understanding of the nature and practices of science, clearly they have engaged in practices that are similar to what scientists do. The next step would be to include activities that help these pre-service teachers explicitly reflect on their own learning and to compare the evolution of their own ideas to the evolution of the ideas within the scientific community. Other curricula [14] has "Learning about our own Learning" activities embedded within the curriculum, as well as activities that guide students thorough explorations of the nature of science, the historical development of ideas in science, and how students' own learning process compares the learning process of scientists.

REFERENCES

1. N.G. Lederman, F. Abd-El-Khalick, R.L. Bell, and R.S. Schwartz, *J. Res. Sci. Teach.* **39**, 497-521 (2002).
2. National Research Council [NRC], *National Science Education Standards*, National Academy Press, Washington, DC 1996.
3. J. D. Miller, *Pub. Und. Sci.* **13**, 273-294 (2004).
4. P.G. Hewitt, J. Suchocki, and L. A. Hewitt, *Conceptual Physical Science* (3rd ed), Pearson Ed. Inc., San Francisco, CA, 2004.
5. D. Lortie, *Schoolteacher: A sociological study*, U. of Chicago Press, 1975.
6. V. Richardson, "The role of attitudes and beliefs in learning to teach" in *Handbook of Research on Teacher Education* edited by J. Sikula, Prentice Hall, Upper Saddle River, NJ (1996).
7. C.S. Weinstein, *J. Teach. Ed.* **40(2)**, 53-60 (1989).
8. NRC, *Inquiry and the National Science Education Standards*, National Academy Press, Washington, DC, 2000.
9. F. Abd-El-Khalick and V.L. Akerson, *Sci. Ed.*, **88**, 785-810 (2004)
10. E. von Glasserfeld, *Synthese*, **80**, 121-140 (1989).
11. V. L. Akerson, F. Abd-El-Khalick, and N.G. Lederman, J. *Res. Sci. Teach.* **37**, 295-317 (2000).
12. R. Khishfe and F. Abd-El-Khalick, *J. Res. Sci. Teach.* **39**, 551-578 (2002).
13. P. Hewson, M. Beeth, and N.R. Thorley, "Teaching conceptual change" in *International Handbook of Science Education* edited by B.J. Frasier and K.G. Tobin, Kluwer, London, 1998.
14. F. Goldberg, S. Robinson, and V. Otero, Physics for Elementary Teachers, 2004