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ABSTRACT

This paper documents a pilot study designed to explore the ideas of high school students regarding the nature and role of theories, an aspect of the nature of science (NOS) that continues to be problematic for students, teachers, and the general public. Although there is a much greater emphasis on the nature of science in standards documents, curriculum documents, and textbooks than there was even a decade ago, those efforts focus largely on the nature of scientific inquiry with little attention on the profound influence of theories on the scientific enterprise and the perspectives of scientists. (Author)

Students' Conceptions Regarding Scientific Theories

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This paper documents a pilot study designed to explore the ideas of high school students regarding the nature and role of theories, an aspect of the nature of science (NOS) that continues to be problematic for students, teachers, and the general public. Although there is a much greater emphasis on the nature of science in standards documents, curriculum documents, and textbooks than there was even a decade ago, those efforts focus largely on the nature of scientific inquiry with little attention to the profound influence of theories on the scientific enterprise and the perspectives of scientists.

Significance

Inquiries into students' and teachers' conceptions regarding NOS have addressed many aspects, including the concept of scientific theory (Dawkins, 2000; Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002). Translating the informal use of the word *theory* (as in "just a theory") to scientific theory clouds the fundamental importance of theory as a basis for scientific work. In addition, it further complicates the discussion related to controversial theories such as biological and geological evolution, obscuring the substantive scientific issues (such as the strength of evidence) with peripheral discussions based on non-scientific or anti-scientific views. (See, for example, Bentley, 2000 and Brickhouse, Dagher, Letts IV, & Shipman, 2000.) Related difficulties include distinguishing between a theory and the evidence that supports it or between describing evidence and interpreting evidence (Allen, Statkiewitz & Donovan, 1983; Kuhn, 1991, 1992; Roseberry, Warren, & Conant, 1992). Identifying the problem in a very specific way paves the way for the design of instructional materials and strategies to address those issues.

Theoretical Underpinnings

Recent literature on NOS focuses primarily on teachers, either pre-service or in-service (Akerson, Abd-El-Khalick, & Lederman, 2000; Abd-El-Khalick & Lederman, 2000; Bell, Lederman, & Abd-El-Khalick, 2000; Hammrich, 1997), although there are a few studies focusing on elementary and secondary students' understandings, most recently by Lederman et al, 2002 and Aikenhead (1988).

In general, studies show that all groups (K-12 students, pre-service teachers, and in-service teachers) have fundamental misunderstandings about NOS that seem to persist unless they experience certain kinds of instruction. Common to most successful interventions is intentional and explicit references to the NOS issues being addressed. Neither teachers nor students have the necessary experience or global perspective to construct profound ideas about NOS from typical classroom science activities, even those that are exemplary inquiry-based lessons; they must have access to explicit information about NOS communicated in a realistic context and arising from a historical and philosophical perspective related by experts (Dawkins and Glatthorn, 1998).

Methodology

The study used an instrument administered by high school science teachers to students in grades 9-12.

Instrument. The instrument consisted of 10 items, each of which presented two opposing statements requiring a forced choice by students as to which best represented their view of science. In addition to a choosing between two options, the students were also asked to explain their choices in a brief open-ended response. For the purposes of this study, responses to the six items addressing the nature and role of theories were analyzed.

Subjects. The subjects were 641 students in grades 9-12 enrolled in public high schools in North Carolina. Sixteen teachers in a professional development network volunteered to administer the instrument to their students. There was no attempt to insure that the students represented the general population of high school students in North Carolina, nor to select students in specific grades or science subjects. The teachers received the survey instrument as an e-mail attachment and made hard copies to give to their students. They returned the instruments by mail to the researchers for analysis.

Analysis and Results

Student choices. Student choices and comments were analyzed by grade level, calculating the percentage of "correct" choices, based on thinking found in current literature on NOS. Student choices for items 5-10 (those related to theories) are represented in the tables below. Student comments are discussed in the next section.

Table 1
Responses to Item 5

Choices:
a. Since scientific theories have not been proved, their use in science is not valued as much by scientists as experimenting with no dependence on pre-existing theories.
b. Existing scientific theories form a basis for the experimental work of most scientists.

Grade	9	10	11	12	Total
n	333	106	89	104	632
% correct (b)	78.0	76.4	75.3	84.6	78.5

Table 2
Responses to Item 6

Choices:
a. The observations made and recorded by most scientists are somewhat *subjective* in that they depend at least in part on the theories that scientists previously accept.

b. Most scientists depend on direct, *objective* observation more than on previous findings or pre-existing theories.					
Grade	9	10	11	12	Total
n	319	100	84	100	603
% correct (a)	58.6	52.0	65.5	74.0	61.0

Table 3
Responses to Item 7

Choices: a. As *theories* are supported by more and more experimental evidence, they may eventually be proved and then become scientific laws. b. No matter how much evidence is gathered in support of a *theory*, it will *not* become a scientific law.					
Grade	9	10	11	12	Total
n	328	102	86	104	619
% correct (b)	20.4	48.0	12.8	14.4	17.3

Table 4
Responses to Item 8

Choices: a. Just as an explorer *discovers* a new island, a scientist may *discover* a theory. b. Just as an architect *invents* a structural design, a scientist may *invent* a theory.					
Grade	9	10	11	12	Total
n	324	98	82	98	602
% correct (b)	40.4	39.8	34.1	37.8	39.0

Table 5
Responses to Item 9

Choices: a. The focus of most scientists' work is to support, enlarge, or change theories that already exist. b. The focus of most scientists' work is the development of new theories.					
Grade	9	10	11	12	Total
n	314	99	77	90	580
% correct (a)	45.2	53.5	49.4	63.3	50.0

Table 6
Responses to Item 10

Choices: a. If there are two competing theories in a particular area, the better of the two is the one that is nearer to the truth. b. If there are two competing theories in a particular area, the better of the two is a matter of agreement among scientists arising from critical review.					
Grade	9	10	11	12	Total
n	325	101	83	98	607
% correct (b)	55.1	58.4	53.0	73.5	58.3

Although the results are reported by grade level, the study does not attempt to draw conclusions in regard to student grade or age. Most teachers participating in the project were teaching an earth/environmental science course required for high school graduation (ensuring a diverse student population) and offered by many schools at the 9th grade level—a situation that accounted for the large number of respondents in the 9th grade. Additionally, there is no evidence to show that grade or age makes a difference in understanding NOS concepts, at least at the high school level; rather, choices made by the teacher to intentionally incorporate such ideas into curriculum and instruction affect student understanding.

Considering the items in order of most correct choices to least, Table 7 summarizes scores and provides comments.

Table 7
Summary of scores

Item #	% correct	Comments
5	78.5	More than ¾ of the students indicated an understanding of theories as a foundation for scientific work.
6	61.0	More than half the students selected a response that characterized scientists as being somewhat subjective by virtue of their working in the context of a pre-existing theory.
10	58.3	Although this item addresses theories, it also focuses on the role of the scientific community. Most students indicated that the scientific community is the ultimate judge of a theory's value, not the "truth."
9	50.0	Half the students thought most scientists work to develop new theories and half indicated that most scientists work in the context of existing theories.
8	39.0	Over 60% of the students show a lack of understanding of the fundamental nature of theories as explanations invented by scientists. Most chose the option that described theories as somewhere out there awaiting discovery.
7	17.3	Not surprisingly, very few students understood the qualitative difference between theories and laws. The responses support previous studies showing that most people think theories can "grow up" to become laws.

In further consideration of Items 7 and 8, the study strongly suggests that these students hold vague notions about the nature of theories. Although most students recognized the important role theories play in scientists' work, a large majority held fast to the idea that theories are inferior to laws and that they exist apart from the creative endeavors of scientists.

<u>Comments of students</u>. Comments supporting students' choices provide additional insight into their thinking. In regard to Item #7 (theory vs. law), main ideas communicated by the open-ended responses included the following:

1. If it can be proved, then it should be a law.

If you can prove it, then it's a law.
I think the more that something is studied the more proven it becomes. We get closer and closer every day to proving things, like clones.
A theory is only a theory until it is proven to be a fact.
I think theories can be proven because some stuff is just common sense.
Theories that are proven are laws.
A theory turns into a law after it is proven so many times.
Law of gravity, time-tested and proven, so why can't other theories become laws?

2. With enough evidence, theories become laws.
The more evidence you have that a theory exists and you can prove it, then it can become a law of science.
Yes, if more evidence is found, the theories will eventually become scientific laws.
The more evidence the better chance it is true.
If enough evidence is gathered to make it a fact, then it should become a law.
Evidence is needed.
Enough evidence may be gathered to form a law if an experiment happens to produce positive repetitious results.
3. We should be skeptical about theories.
A theory is something believed such as plate tectonics, but it is not a scientific law.
Unless it involves definite mathematics I feel it is all speculation.
They proved the earth was flat, so even if proved, it may not be true.

These comments (and others) reveal a cluster of concepts that are wrapped up in the theory/law discussion--evidence, proof, facts, experiment, belief—all of which hold potential for further research into students' conceptual understandings.

Comments related to Item 8 (invention vs.discovery) include the following:

<u>From those who chose "theory as discovery."</u>
It's something that's already there.
You can't just invent a theory because it could not be true.
A theory is discovered, not invented because the information is always there, just must be found.
You can't invent a theory, you just first discover the evidence to conclude a theory.
It's all about discovery, kinda like the channel.
Little bits and pieces help "discover" new things. Invent is made up!
A theory has to have evidence behind it, so it cannot be invented.

From the comments, many students rightly assumed that theories require supporting evidence, but they lacked a fundamental understanding of theories as explanations that arise from evidence.

From those who chose "theory as invention."

Theories generally begin as ideas in the mind of the scientist, you can't discover an idea.

I think you invent theories because it's your own idea, you just have to prove it.

I don't think you can discover a theory because a theory is a belief.

Scientists don't discover theories; they create them inside their minds with their own perspective and insight.

These responses show that, even among students who chose the "correct" response, there remain naïve understandings of concepts, an important consideration in drawing conclusions from tests such as this one without opportunity to obtain more information through written or verbal comments. Their comments, like those of the students who chose the "incorrect" answer, fail to show a deep understanding of theories as explanations of natural phenomena. The student sample for this study was based on convenience for the researchers, but the results are consistent with previous findings, and provide dramatic confirmation of students' misunderstandings about important aspects of the nature of theories.

Implications

Studies show that misunderstandings about the nature and role of theories are wide-spread among teachers (and often perpetuated in science textbooks). Until clear, reliable information is presented in science teacher education programs (pre-service and in-service) and in textbooks, student conceptions will continue to reflect those of the general public. From the literature on learning (specifically constructivism), it is relatively easy to devise interventions that work, allowing teachers and students to investigate the nature of theories by exploring existing theories from a historical perspective. If they ask the right questions about theories such as theory of evolution, atomic theory, or theory of plate tectonics, they can derive for themselves (with a good facilitator) the main characteristics of theories, such as . . .

1. They are explanations (not descriptions, as are laws)
2. They are only as strong as the evidence that supports them
3. They change as new evidence emerges
4. They are useful in predicting
5. They do not need to be "proved" in order to be valuable.
6. They provide a context for research

The current practice seems to be to address theories in general without referring to theories in specific, but there are many successful strategies documented for clarifying the concept through attention to the development and use of specific theories that exist today or that existed some time in history.

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