

# Surveys Fail to Measure Grasp of Scientific Practice

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**Abstract.** There is debate in the science education literature about how best to improve students' understanding of the nature of science: Can an “immersion” experience in the process of doing science like scientists outperform explicit instruction on the nature of science? Central in resolving that debate is the development of appropriate measures of students' understanding of the nature of science. We report on a course in which students engaged in sophisticated scientific practices, and yet student responses to a standard nature of science survey showed surprisingly few pre-post changes. We argue that this data suggests that when students do science like scientists do, they gain a grasp of scientific practice that cannot be measured by declarative means such as surveys and interviews.

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## INTRODUCTION

Students at all levels have demonstrated a poor understanding of the Nature of Science (NOS) despite decades of efforts to change this state of affairs [1]. The best instructional practices for improving NOS have been hotly debated. One approach argues that students who engage in doing science through inquiry will necessarily develop more sophisticated understandings about NOS. Such an “implicit” approach is the experience of practicing scientists who, through their immersion in the daily practice of science, come to better understand scientific epistemology. In contrast, an “explicit” approach uses hands-on activities that highlight NOS ideas, followed by reflective discussions and writing to draw out the connections to targeted NOS themes. For instance, students might explore an ‘Inquiry Cube’ [2] as a way to trigger discussions about the distinction between observation and inference.

However, the scientific inquiry found in classroom settings is so varied and typically so unlike authentic scientific practice, that determining whether an implicit approach leads to improved NOS understandings is difficult. As Sandoval [3] points out, “much of the practice to look at is so obviously school science and so unlike professional science that we have no real hope to ...study anything other than epistemologies of school science” (p. 645).

There is, then, a need for examining the development of students' ideas about NOS within a context that allows them to engage in authentic scientific practices. A recently developed course, *Scientific Inquiry*, was designed to provide this context [4]. The course is solidly grounded in the implicit approach to developing NOS understandings --

students were presented with complex observable phenomena (such as a cow eye, color mixing, rubber band guitars, or a pinhole camera) and challenged to develop scientific explanations and theories in the same ways that practicing scientists might: by asking questions, constructing models, designing tests of those models, engaging in debates, writing up and presenting their findings, and critiquing one another's work. Students in the course became a scientific community, alternating between student-driven research in teams of three or four students and whole class discussions where students present and critique one another's work and discuss scientific ideas.

## METHODS

Data was collected from 15 Liberal Studies majors (all female; 12 seniors, 3 juniors; all but one plan to become K-8 teachers) enrolled in *Scientific Inquiry* at our mid-sized state university. The class met five hours per week over a 15-week semester. Students take this course after completing an introductory sequence of three science content courses as one of two options to fulfill their upper-division science requirement.

Students completed a frequently used open-ended NOS survey, the Views about the Nature of Science, Form C (VNOS) [5], before and after the course. A copy of VNOS is available at [http://www.flaguide.org/tools/diagnostic/views\\_of\\_nature\\_questionnaire.php](http://www.flaguide.org/tools/diagnostic/views_of_nature_questionnaire.php). Responses were analyzed and coded following the general methodology of Schwartz and Lederman [6] who analyzed the responses of practicing research scientists on a VNOS survey. Subthemes emerged from our students' responses upon a first reading and were refined through further rounds of analysis. Pre- and post- comparisons of each individual's

conceptions were conducted and scored by a qualitative measure of the degree of change (none, slight, or large change). The small sample size precluded the use of statistical measures.

## RESULTS

Table 1 lists the themes and subthemes that were identified and illustrates each with a representative student quote. Subthemes are non-exclusive. For instance, students can simultaneously believe that creativity is required in the design of new experiments

and in coming up with new questions to investigate.

Students showed remarkable consistency in their responses between pre- and post-test, despite their experiences doing authentic science. Table 2 shows the number of students holding each view before and after the course and indicates the number of students who showed no change, a slight change or a large change in their view with each theme. *In all theme areas, the vast majority of students showed no change in their views.*

The almost word-for-word similarity between students' responses at the beginning and end of the course was startling. For example, consider Amy's

**TABLE 1.** Themes, Subthemes and Example Quotes

NOS Theme	Subtheme	Representative quotes
<b>Empiricism</b>	Yes - experiments/observations lead directly to facts, certainty and proven truths	Scientific knowledge needs to have proof. Experiments help solidify scientific ideas, but they also help alter or disprove ideas.
	Yes - experiments/observations allow us to figure out how/why things work (and can prove to others)	You can't explain and convince someone how something works if you haven't personally worked with something of relevance. You need to work with the product or idea you are trying to explain.
	Yes - experiments/observations help individuals to learn better and prove to self	Sometimes [experiments] can help you learn better. I'm more of a hands on person. I feel that personally for myself it helps me understand a concept better.
	No - science is everything (incl. religion, philosophy)	I think science is basically everything... Science has little difference compared to religion or philosophy, those too are a science but less experimental and more thought-process based.
<b>Process</b>	Scientific method - sequential steps to follow	An experiment is part of the scientific method that was created by scientist to regulate what is and is not a proven theory of the universe. The scientific method has 4-5 steps that break down whether something is going to be a law of how things work on the planet.
	Science fair - answer a question; variables to control; test a idea/ theory to prove if right or wrong	An experiment is anything that involves variables that are being tested, altered, observed or changed. [An experiment is] a highly specific test to see if an idea about something is true or not.
	Give support or evidence to a theory or idea; come up with a new idea; make discoveries	An [experiment is an] attempt at discovering a new idea. They are used to support theories. Experiments are the only way to keep science uncovering new ideas and perceptions about the world we live in.
<b>Tentativeness</b>	Yes - (no durability) theories change all the time	Yes; theories can change all the time. A theory is just that, a theory- not a fact. theories, generally speaking are always subject to change.
	Yes - (durability) theories change with new evidence	Some theories can change, but it takes a lot of observing, researching, and experimenting... Theories only change when someone comes up with enough evidence to disprove the current theory.
	No - theories proven to be true	Once a theory is developed, like evolution, the theory is never changed. A theory isn't changed because communities of scientists have been gathering research and data to come out with conclusions that they have agreed on and disagreed on until everyone came out with similar results.
<b>Subjectivity</b>	Yes - will believe whatever want to	[What you think] depends on how you interpret the information... For example when we look at clouds. Someone might say it looks like a rabbit one person may say it looks like a car. It all depends on the individual.
	Yes - diff underlying theories lead to bias/ diff ways to interpret same data	There are two possible conclusions because they are two separate theories... If different people think differently than it is possible to come to separate conclusions, especially if we have no way in knowing for sure.
	No - ultimately data will tell you (data not good enough or both ideas must be right)	The two groups of scientists could have come up with different conclusions for the explanation of the dinosaur extinction because they would be studying the same rock samples. Neither of them was there for the event, so it would be easy to have different views. Maybe a meteor rock is similar to a volcanic rock. From the rock sample, the scientists could have made different conclusions.

**TABLE 1.** Themes, Subthemes and Example Quotes (continued)

NOS Theme	Subtheme	Representative quotes
<b>Context</b>	Yes - affects process (funding, who can do science, what experiments to do)	Although science is meant to be as objective as possible, I believe that social, political, and philosophical values contribute to science. One example that I can think of is the funding of scientific research... Funding of certain "valued" projects leads to more research in those areas as opposed to less valued areas.
	Yes - affects interpretations (reasoning, assumptions, what conclusions open to)	In Galileo's time it was heresy to say that the sun was the center of the universe, and that the earth revolves around the sun.
	Depends - not supposed to be but sometimes is	Because science is conducted by humans, there is always the potential for hypotheses to reflect the cultural setting... But scientists do their best to think of these considerations and account for them. This is also why peer review and repeatability of the experiment is so important. When conducted with a minimum of subjectivity, repeated, and confirmed, science can clearly produce facts that are true in any place or time regardless of culture.
<b>Creativity</b>	Yes - in designing experiment	The design of the experiment definitely has to be out of the ordinary and creative to test its ability in the world. If you aren't creative during planning, no new interesting theories could ever be created.
	Yes - in coming up with new questions/ideas	Coming up with something that no one else has thought of yet, or trying to disprove an idea because you think you have the right explanation, that takes creativity.
	Yes - in interpreting results/generating explanations	Scientists must look at reality in a unique way in order to derive new hypotheses or fit existing scientific knowledge into theories. An example of creativity in science is Darwin's observation of finches in his derivation of the theory of evolution. Darwin used his imagination to tie together similar looking birds with specific differences. Imagining that slight differences in beaks, behaviors and colors may be adaptations within one species contributed to Darwin's recognition of evolution of subspecies.
	Yes - in collecting/presenting data	Scientists use creativity... in writing, bullets, charts, graphs, drawings and when they present their investigation.

response to the question: "What is an experiment?":

*Pre-course:* "An experiment is something that tests out an idea that you are trying to prove. An experiment uses different variables and controls to test out an idea or thought."

*Post-course:* "An experiment is when you test something to prove whether or not your idea is true or false. You have various variables and controls to test an idea that you have."

Her statements are almost identical in their phrasing. Moreover, we never explicitly discussed controlled experiments and variables in the course, nor did Amy's own investigations approach experimentation as "proof." Rather, during class we observed how Amy, like other students [4], use experimentation as part of a purposeful and cyclical interplay between questioning, generating, testing, refining, and discussing ideas and explanations. Amy appears to be drawing from a definition of the word "experiment" that she learned previously; one that she did not appear to enact in her own scientific investigations.

Instances of large changes in students' responses were few and far between, never more than three students in any one theme area. There were only three categories of changes that had a notable number of students making the same shift. Five students shifted from thinking that creativity is only used for experimental design to considering other uses of

creativity as well. Four students shifted from believing that experiments lead directly to facts and proven truths to some other subtheme. Finally, four students shifted from thinking that the process of science must follow a rigid step-by-step scientific method to a different, more flexible subtheme.

Large shifts were distributed across individuals. No individual showed large changes in more than two theme areas at the same time.

## DISCUSSION

The findings from the NOS survey and the interviews with students initially surprised us. We had witnessed these students using experiments, data, and theories in sophisticated and scientific ways [4]. Why wouldn't this be apparent with the VNOS survey?

We have come to realize that the use of surveys to measure students' NOS understanding relies on the assumption that these understandings are a form of declarative knowledge (knowledge about science in general that can be expressed as a statement). Such an assumption overlooks the possibility that "doing science" is a form of procedural knowledge (knowledge of how to engage in scientific inquiry within a community of practice). As Hammer and Elby [7] state, "Questioning students in [declarative] ways

**TABLE 2.** Pre-Post Change

NOS Theme	Subtheme	# Pre	# Post	# no change	# slight change	# large change
<b>Empiricism</b>	Yes - experiments/observations → facts and proven truths	11	7			
	Yes - experiments/observations → how/why things work	5	6	10	4	1
	Yes - experiments/observations help individuals learn and prove to self	2	3			
	No - science is everything (incl. religion, philosophy)	1	1			
<b>Process</b>	Scientific method - sequential steps to follow	4	1			
	Science fair - answer a question; variables to control; test a idea/theory	8	9	9	3	3
	Give support to a theory or idea; come up with a new idea; discoveries	4	5			
<b>Tentativeness</b>	Yes - (no durability) theories change all the time	3	2			
	Yes - (durability) theories change with new evidence	11	10	12	2	1
	No - theories proven to be true	1	3			
<b>Subjectivity</b>	Yes - will believe whatever want to	2	2			
	Yes - diff underlying theories lead to bias/diff ways to interpret same data	7	4	11	4	0
	No - ultimately data will tell you	9	10			
<b>Context</b>	Yes - affects process	4	5			
	Yes - affects interpretations	2	3			
	Depends - not supposed to be but sometimes is	2	1	8	3	3
	No - science is universal (gravity is gravity)	10	10			
<b>Creativity</b>	Yes - in designing experiment	13	11			
	Yes - in coming up with new questions/ideas	7	7			
	Yes - in interpreting results/generating explanations	5	7	8	5	2
	Yes - in collecting/presenting data	3	2			

about their epistemologies may be, to borrow an old joke, like interviewing golfers about their swings, off the course and away from their clubs: ‘Do you inhale or exhale when you swing the club?’ It is not something they talk about ordinarily, and they may not know the answer.” (p.4)

Thus, it may not be surprising that our students failed to show notable changes on a survey. Analysis of students’ investigations and classroom conversations indicates that they develop a far more sophisticated NOS understanding than these survey measures show [4]. Recently completed discourse analysis shows that over the semester, students respond to data and new ideas in increasingly expert ways [unpublished data]. For instance, in the first week of class, students casually discard one theory for another; ten weeks later, when confronted with two opposing theories, students talk out their differences, presenting more and more supporting lines of evidence until the whole group is convinced.

What is required are assessment tools that monitor the development of procedural knowledge, an implicit “grasp of practice” [8], that students call upon when they encounter a puzzling phenomenon or another student’s scientific claim even if this does not extend to students knowing what to say in response to a survey or interview question.

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## REFERENCES

1. N. Lederman, “Nature of science: Past, present, and future” in *Handbook of research on science education* edited by S. Abell and N. Lederman, New York, NY: Routledge, 2008, pp. 831–879.
2. National Academy of Science, *Teaching About Evolution and the Nature of Science*, Washington, DC: National Academies Press, 1998, pp. 66-73
3. W. Sandoval, *Science Education*, **89**, 634–656. (2005).
4. I. Y. Salter and L. J. Atkins, *Journal of Science Teacher Education*, **Online First (Sept. 7, 2011)**, 1-21. (2011).
5. N. G. Lederman, F. Abd-El-Khalick, R. L. Bell, and R. Schwartz, *Journal of Research in Science Teaching*, **3**, 497-521. (2002).
6. R. Schwartz and N. Lederman, *International Journal of Science Education*, **30**, 727–771. (2008).
7. D. Hammer and A. Elby, “On the form of a personal epistemology” in *Personal epistemology: The psychology of beliefs about knowledge and knowing* edited by B. Hofer and P. Pintrich, Mahwah, NJ: Erlbaum, 2002, pp. 169–190
8. M. Ford, *Science & Education*. **17**, 147-177. (2008).