Evaluating Learning about the Nature of Science in a Research Experiences Program

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Laboratory or field research experience offers us an alternative pedagogical model to classroom instruction. Generally, research experience is reserved for graduate students who have mastered much of their subject and are prepared to embark on self-guided learning. However, undergraduates can also participate in research and in some cases can gain a great deal from it. Research experiences are widely believed to be an important mechanism for recruiting undergraduates into science careers and for giving students an opportunity to test their interest in research (NSF, 1996; Mervis, 2001). Student learning in a research experience is different from a classroom experience many ways. The content knowledge that that student must master is generally more in depth than typical course work but much more limited in scope because it must be highly focussed on the research project. In addition, students must master a particular set of research skills that usually are in some ways independent of the content knowledge that they are learning. Research experiences tend to be highly personalized and unstructured compared to the classroom environment; expectations regarding the final outcome (poster presentation, paper, data, samples etc.) are particular to each program. Therefore, assessing in some standardized way, what content knowledge students have learned from research experiences would be very difficult.

From our own early research experiences, we know that we learned much more than what was explicitly taught to us. A research experience involves an enculturation (Kardash, 2000) or socialization process (Hogan and Maglienti, 2001) where students pick up styles of speaking, the structure of explanation, and attitudes towards science from their mentors (Bleicher et al., 1996). In other words, the common element that students learn in a research experience is what research is and how it is done. We hypothesize that examining changes in knowledge of the nature of science could form a basis upon which to measure and compare the effects of different kinds of research experiences on undergraduates.

As part of the Atlanta Consortium for Research in the Earth Sciences (ACRES), we run an NSF funded summer research experiences program at Georgia State University in Atlanta. The program takes 12-15 undergraduates as teachers for 8-week period each summer. The participants work in teams on four different geoscience research projects. The summer program also serves as a test bed for our efforts to understand and learn to quantify the impact of research experiences on undergraduates.

Survey Instruments

Knowledge of the nature of sciences has typically been treated, like knowledge of other subject matter, as something that can be measured by objective instruments (Hogan, 2000). Many tests and inventories have been developed that compare respondents understanding of the nature of science with the nature of science as understood by those developing the instruments. In order to ensure that instruments are valid, instruments are written such that there will be agreement among science educators and in some cases scientists about what the "correct" answer is. However, there does not appear to be uniform agreement as to what the nature of science actually is. Philosophy of science presents us with widely divergent views regarding the nature of science. Although the extent of disagreement is debated (Elfin et al., 1999), modern philosophers hold somewhat different beliefs about of the nature of science than those held by science educators (Alters, 1997). The views of practicing scientists are different from those of both philosophers and science educators (Pomeroy, 1993). In addition, there is good evidence to suggest that geoscience is not identical in nature to other sciences such as physics and chemistry (Ault, 1998; Frodeman, 1995; Peters, 1996). Certainly, one can easily determine via a casual conversation with one's colleagues that geoscientists hold a range of opinions about the nature of geoscience. Therefore, the task of developing an instrument with a key of "correct" answers is fraught with questions about the validity of the questions as well as their answers. The result is that many of items in existing instruments are very general, capturing science in its broadest form. On the instruments that we experimented with, we found that adults could pick the "correct" answers independent of their science experience.

Our approach to the "no right answer" problem is to stop thinking of the instrument as a test but instead think of it as an instrument like an oscilloscope that measures a signal. We do not expect an oscilloscope to render an exact replica of what it measures but rely instead on calibration with known input signals. In this case, our "signal" is the distribution of opinions about the nature of geoscience that a given population holds. We reason that we should therefore compare the "signal" that we get from undergraduates engaged in research to the "signal" we get from a population of geoscientists.

We have been working to develop our own instrument (Statements About Science Instrument (SASI)) for measuring undergraduates' (as well as science teachers involved in our program) understanding of the nature of science. The new survey instrument is based on clusters of statements representing a variety of philosophical positions, from which respondents must pick one statement.

For example:

a) Science is a collection of true facts.
b) Science is a procedure.
c) Science is a world view.

a) When examining data, logic is more important than creativity.
b) When examining data, creativity is more important than logic.
c) Examining data requires only logical thought.
d) Examining data requires only creative thought.

a) Science assumes cause and effect.

b) Science assumes nothing.

We compare the distribution of the choices made by a group of respondents with the distribution of choices made by geoscience faculty. The first version of the instrument was able to differentiate between three different groups of students with different science backgrounds. Some of the statement clusters detected changes in our research experience participant's attitudes over the course of a summer. For example, the percentage of participants who considered science a world view (cluster 1 above) and the percentage who considered science independent of culture became more like the faculty by the end of the summer. We believe that with further modification, an instrument can be developed that will detect changes induced by participation in a research experience.

Open ended-questions

We have also experimented with the use of the following open-ended questions:

1. What does it mean to study something scientifically?
2. What is a theory?
3. How can one distinguish good science from bad science?

Question 1 is borrowed from the National Science Board's Science and Engineering Indicators project, which has occasionally asked this question of a random sample of American adults (National Science Board 1993, 1998, 2000). Questions 2 and 3 were developed by us. Responses to the questions were analyzed using WordStat, a software package for text analysis.

Responses to question 1 were coded according to the same criteria used by the National Science Board (1993, 1998, 2000). A response was coded as adequate if it touched on the role of theory-building or -testing, the use of experiments, or the application of rigorous comparison. In pre- and post- testing of participants in our research experience program we found that the number of individuals providing an adequate answer increased from 62.5% to 88.9%; a statistically significant increase ($X^2 = 4.50$, df = 1, $p < .05$). In comparison, only 20% of a group of education graduate students that we tested provided adequate answers to this question.

Responses to question 2 were coded in terms of whether or not a respondent reported that theory was more than a guess or an opinion. Only 12.5% of participants in our research experience program initially responded that a theory is no more than a guess or an opinion and only one participant, or 5.6%, responded this way at the end of the experience. In comparison 42.1% of a group of education graduate students indicated that a theory was little more than a guess or an opinion.

Responses to question 3 were coded in terms of whether or not the respondent made reference to scientific method, the need for objectivity, or the application of peer review. Responses were also coded to assess whether or not the participant made any reference to social or ethical factors. In pre- and post- testing of participants in our research experience program we found that there were no changes at the end of the program; 87.5 % percent of participants offered adequate answers. In comparison only 42.1% of education graduate students answered this way. 16.7% of participants in the research program mentioned at least one social or ethical factor, which increased slightly to 21.1% at the end of the program. No education graduate students mentioned social or ethical factors although some mentioned other factors including inclusiveness and “hands-on”.

The use of open-ended questions to probe participants’ understandings of scientific processes holds promise. We find that those who have chosen to participate in a research experience program are well-prepared to grapple with such questions, and that their open-ended responses provide potentially rich data regarding their cognitive models of science. Although most of the changes we observed were not statistically significant, many of the differences between the education students and the participants in the research program were significant. The changes in responses to question 1 between pre- and post- testing were also statistically significant. We are currently experimenting with additional open-ended questions and plan to examine the resulting textual data for evidence of particular beliefs and the use of particular terms. Hopefully, this will allow us to determine how and why a research experience may be cultivating specific views regarding science.

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