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Science Education: Challenges and Contradictions in the Preparation of Science Teachers and Curriculum

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Abstract: Curriculum goals that promote child-centered inquiry learning in science classrooms can only be met if teachers believe both in the pedagogy promoted and in the perspectives on science represented in that curriculum. Apart from those issues, an inquiry-focused curriculum requires teachers to engage their students in activities (such as inquiry investigations) that they themselves may not have experienced. This paper reports on findings from two complementary studies that investigated secondary science student teachers engaging with inquiry activities from two different perspectives: as investigators conducting an inquiry, and as evaluations of inquiry work done by others. Findings from these studies suggest that there are considerable challenges to be faced in having inquiry enacted in classrooms.

Keyword: science education, child centered inquiry, inquiry focused curriculum, inquiry activities, science learners

Introduction

It can be argued that the purpose of science education is to develop different ways of looking at the world. In the first approach, students focus on that which is already known from science. They do this by engaging in confirmatory laboratory activities (sometimes called "cookbook" labs) that are designed by teachers, curriculum designers or textbook writers, and by participating in classes that are lecture-oriented, in which they engage in rote learning.

In the second approach, students take an expansive view of the world, learning to look beyond what is already known and learning about what might be possible, what might be found. The types of classes that are structured in such a manner as to develop the second approach to look at the world are often called inquiry-oriented science classrooms. These silence classrooms minimize rote-learning and memorization and instead engage students in investigations about the natural world, from which their understanding of concepts will be developed.

Science Reform Attempts in North America

Inquiry-oriented classrooms better promote the learning of science concepts in addition to more accurate understanding of the material and social practices of science (also referred to as the Nature of Science or NOS), various documents for reforms have been produced in North America by those calling for elementary and secondary science classroom to adopt such a child-centered inquiry approach. These reform-oriented documents include those produced by the National Research Council (NRC, 1994, 1996, 2000), the American Association for the Advancement of Science (AAAS, 1993), the National Council for Teachers of Mathematics (NCTM, 1989), the Council of the Ministers of Education of Canada (CMEC, 1997), and the Ontario Ministry of Education (Ministry of Education and Training, 1993).

There are some differences across these documents, but remarkable similarities both in their content and in their recommended approach does exist as to how classes should be taught. As an example of the content and practice perspective found in these documents, the NCTM (1989) recommends that the grade 5 -8 math curricula should enable students to describe and represent relationships with tables, graphs, and rules (p. 98); analyze functional relationships to explain how a change in one quantity results in a change in another (p. 98); systematically collect, organize, and describe data (p. 105); estimate, make, and use measurements to describe and compare phenomena (p, 116); construct, read, and interpret tables, charts, and graphs (p. 105); make inferences and convincing arguments that are based on data analysis (p. 105); evaluate arguments that are based on data analysis (p. 105); represent situations, and number patterns with tables, graphs, verbal rules, and equations and explore the interrelationships of these representations (p. 102); and analyze tables and graphs to identify properties and relationships (p. 102). The Ontario Ministry of Education documents are also typical of the calls for reform, recommending that a child-centered constructivist approach be taken by the teacher in the classroom explaining that:

> *Effective learning involves actively constructing the meaning of one's world [and it] occurs most effectively when learners are encouraged, individually and in groups, to explore phenomena in their natural and social*

> *environments; to formulate questions for inquiry; to seek answer through observation / experiment. ..[and] research [in] consultation with those more knowledgeable than themselves. (Ministry of Education and Training, p. 5)*

The OMET document further explains that the suggested "consultation" engaged in by students should allow them to present, explain and justify their conclusions, evaluating both the process in which they participated and the conclusions they reached, through discussion with both their peers and their teachers. In general, these documents argue that such approaches should be taken because they improve science and data literacy in students, such that they will have a better understanding of science concepts, science practices, and the manner by which science claims are constructed by scientists themselves.

In discussing the various merits of the different classroom approaches followed in science education, the following dichotomous questions have been found while considering the benefits of one classroom environment over the other:

Which do you consider to be more important?

a) that children can recite the five useful and important things about a magnet, or

b) that children, given a piece of metal that happens to be a magnetic, can figure out five interesting and useful things about that piece of metal?

Most parents and administrators when asked this question indicated that the second scenario would be far more important. Yet, rote memorization-oriented classrooms (which are quite common) are quite good at developing the first, and poorly develop the second scenario. Inquiry-oriented classrooms are good at developing the second scenario, and discussions within the class after students have worked at an inquiry activity can subsequently develop the list of useful things delineated by the first scenario.

In practice, in an inquiry-oriented classroom the following characteristics prevail:

- The problem being investigated by the student(s) is ill-defined, allowing room for, revision throughout student engagement with the problems

- The classroom allows students to experience the uncertainties and ambiguities of drawing conclusions (as is typical in "real" science)
- The current state of knowledge of students is used to set starting position for an acceptable project
- Material and discursive practices and resources are shared and developed as part of the community of learners (drawn from Roth & Bowen, 1995)

Despite being described in reform documents and promoted in faculties of education in North America for almost two decades, the adoption of these practices into the classroom has been quite slow (Furtak, 2006; Roehrig & Luft, 2004; Wallace & Kang, 2004; Reiff, 2002). Explanations for this cover a variety of considerations, including teachers views about the practice of science (Bencze, Bowen & Alsop, 2006), lack of time (Loughran, 1994), beliefs about science and pedagogy (Wallace & Kang, 2004; Gess-Newsome, 1999; Pajare, 1992; Ernest, 1989) lack of clear understanding of inquiry (Roehrig & Luft, 2004; Windichitl, 2004), institutional constraints (Bencze & Hodson, 1999), and a limited understanding of the Nature of Science and how to develop it through classroom activities (Brickhouse, 1990; Abd-el-Khalick, Bell & Lederman, 1998).

Current Research Directions

The research agenda in which I am engaged (with the participation and support of my Colleagues J. Lawrence Bencze, Anthony Bartley, and Patricia Hembree) examines an aspect of this problem that is little researched by others: the experiences with inquiry and the: associated practices that student teachers have had. The first insight we had that (pre-service) teachers may not themselves have experience with the practices that the reform documents promote emerged from a study which identified that there were problems with pre-service science teacher analysis of data, data of the sort which would be (and in this case, had been) collected by students in an inquiry investigation. In this study (Roth, McGinn & Bowen, 1998), pre-service teachers were asked to analyze a data set of paired data (light intensity and bramble density) presented to them on a map (representing the locale in which the data had been collected). Such an activity is common to the practice of science, but the conclusion from this study was that "pre service teachers [with Bachelor of Science degrees], despite their strong background in science, did not use the representative practices in the way practicing scientists do" (p. 43), or, perhaps equally, significantly, with any more complexity (and in some ways less) than did grade 8 students who had participated in an open-inquiry science classroom environment. This suggests that pre service science teachers do not, themselves, engage in the data-related practices that reform documents expect them to teach to their own students. Subsequent studies (such as Brown & Roth, 2003) also suggested that such interpretation problems were consistent across settings.

Apart from the importance placed on inscriptions (both data tables and graphs) in the afore mentioned reform documents, data interpretation and analysis is also a key component of engaging in research activities in science, and the canonical (and effective) use of inscriptions is central to these activities (Latour, 1987). Thus, the case that canonical use of inscriptions is central to inquiry-oriented classrooms is easily made. In the following sections, this paper will present summaries of two recent research projects conducted in order to better understand difficulties that student teachers have with practices involving science inquiry. These two studies represent different perspectives on practices with inquiry in that one discusses "inquiry literacy" from the perspective of engaging in an inquiry activity, and the other discusses it from the perspective of evaluating an inquiry activity. In their entirety, and given the preceding, we conclude that a further reason that inquiry practices are not engaged in by teachers is that they themselves do not engage in the practices of inquiry when given the opportunity, arid thus they would find it difficult to scaffold their own students to success in such practices.

Engaging!! Student teachers in conducting a long-term inquiry investigation

As part of a 6-month long inquiry-oriented science teaching methods course, participating students (all of whom had BSc degrees) took part in a self-directed, long-term inquiry activity called the "Rotting Grass Lab" (RGL). In the first week of the class students obtained a "handful" of grass and placed it in a beaker of pond water. Their job was to observe and document changes in the beaker over the following five months (some class time was allotted for this task, and they were also expected to use out-of-class time). They were responsible for a number of tasks, including:

- making labeled biological drawings of organisms in the beaker;
- drawing diagrams of changes in the beaker;
- collecting both quantitative and qualitative observations of biotic and abiotic features of the beakers' contents and examining relationships between them;
- collecting details of plant, fungal and protist communities in the beaker, and engaging in (written) discussions of observed and empirically supported relationships between them;
- making measurements to show trends in various variables over time (which they were to summarize both in tables and in graphs)
- recording details of the local environment affecting their beaker; and,
- making comparisons (both qualitative and quantitative) with the organism communities in the beakers of other members of the class.

The types of information they were asked to keep track of were similar to that which field ecologists collected during field research (Bowen & Roth, 2007) and thus represented 'authentic' research outcomes. Students were to record all of their observations and representations in an individual logbook/diary, in which they were to keep written observational notes, questions they had, issues that arose, and so forth. In other words, the logbook was to be a combined experiential diary and research logbook.

The RGL activity was chosen because it offered opportunities for individuals with varied backgrounds in science to engage in inquiry and collect data that represented their individual background strengths (e.g., plant biologists, microbiologists, chemistry, physics, etc were all possible backgrounds which could engage in studies with the beaker); in their groups of three, they were expected to exploit the backgrounds of each member. The course instructor and teaching assistant were available both during the laboratory time allotted for conducting the observations as well as at other times that the room was available to them (when it was not in use by other instructors). At the midway point of their data collection, the students' logbooks were collected and detailed feedback was provided to the students on their progress. Photocopies were made of their logbooks at this point; the logbooks were returned, and then collected and graded again at the end of the course.

We subjected the logbooks to a detailed content and quantitative analysis. Over the six months that information/data was recorded in the study the following observations 'were made about an "average" 4" x 6" logbook (a more detailed analysis of the data can be found in Bowen and Bencze, 2006):

i) fewer than 8 written questions were present

ii) less than 1 graph and 1 table was present (data observations were made textually and not in tables; even when the same data was collected each week it was recorded as sentences)

iii) approximately 40 pages of notes/observations/diagrams were recorded

iv) 24 "detailed" and 16 "simple" drawings were present (avg. 1 drawing per page)

v) 16 physical characteristics were recorded (so, for instance, temperature every week for 16 of the weeks, or temperature and water height every second week for 16 weeks)

A detailed analysis of the questions suggests that they were more or less equally split between "identification" questions ("I wonder what organism this sketch is of?") and "relationship" questions ("I wonder what this organism eats?"). Examination of the data that were collected revealed that students rarely collected data which would have allowed them to ask questions dealing with covarying interval-ratio relationships (e.g., whether the population numbers of one species varied with pH for instance) other than temporal ones (tracking pH or temperature over time).

Overall, we felt that the data-collection opportunities were tremendously underexploited. Student teachers collected much data that was "unstructured" (drawings, one-off observations), but little that was structured, incremental, or sequential, such that would allow patterns or trends to be identified and discussed. Given the considerable changes in a multitude of factors in the, beaker environments over time, and the amount of class time (over many months) devoted to this activity (not to mention the feedback for improvement provided by the course teaching assistant at the half-way point) we were surprised by the lack of structured data. Another startling aspect was the lack of use of canonical science data or theory in either the logbook notes or the summary conclusions drawn from them. Relationships such as predator-prey relationships were not discussed, nor were concepts such as decomposition. Although many students indicated in interviews that they enjoyed the activity, numerous others indicated that it was of little interest to them. The latter group seemed disinterested in the conduct and practices of science, and the concomitant construction of science knowledge, but seemed to place the most value to being known as authorities 'about science "facts" and concepts known from the research of others (i.e., canonical science knowledge). With the exception of those that had planned to enter teaching early on, we were left wondering why many of our students took a biology undergraduate degree in the first place, given their level of disinterest in actually participating in a biology study within which they had considerable latitude to follow their own interests.

Engaging Student Teachers in Evaluating Inquiry

A critique of the first study that could be offered is that teachers do not "do" inquiry; they evaluate the inquiry work conducted by students. Following this logically, perhaps a better way of determining competency with inquiry activities would be to study the evaluation practices in which pre-service teachers engage when examining inquiry work that has been conducted by students. The following is a summary of findings from a study (Bowen & Bartley, in press) wherein pre-service secondary science teachers examined and provided formative feedback on self-directed open-ended inquiry projects which had been conducted by grade 12 biology students.

Students from a local high school which used a problem-based learning/inquiry approach to teaching science from Grade 9-12 submitted laboratory reports from studies they had conducted to an on-line journal for review (and, ultimately, publishing). Student teachers in a secondary science methods class (all of whom had BSc degrees) acted as formative reviewers for these submissions and wrote feedback which they expected would be returned to the high school students. Their feedback was supposed to allow the high school students to revise their reports so that the best reports possible from the data they had collected would be published (in other words, they could not suggest re-collecting the data under improved conditions). Feedback on improving the writing but not re-doing the research would be consistent with directing students towards using the "hedging" language (Lakoff, 1972, Hyland, 1996, Crompton, 1997) utilized by scientists to describe research conducted in a less-than-ideal fashion, or in drawing conclusions which were tentative to varying degrees.

Individual student teachers were provided one high school student inquiry report. They were instructed to read the report over, noting issues in the writing, representation of data, drawing of conclusions, or implications of the study. They were to then draft a response to the student, highlighting the issues that they had identified and offering praise where they felt that the study had been well done or the report had been well written. Student teachers then participated in a video-taped interview about the report they had viewed and the feedback they provided.

The feedback from the student teachers on the written sections of the high school student reports was generally effective and appropriate. For instance, in cases where the "methodology" section was sparsely written, the pre service teachers noted that the section needed more detail in order for a reader who was not part of the classroom to be able to understand the methodology that the high school students had used. Interestingly, in the interviews they often reported feeling that they were unable to provide feedback because they did not know the specific instructions that had been provided to the high school students. Clearly, their orientation was towards providing feedback for successfully attaining "local" practices, as opposed to those practices that are more broadly accepted in science communities. This was perhaps most evident in the area of data representation in tables and graphs. All of the high school student reports had non-canonical approaches to both the construction of tables and the representation of data in graphs. For instance, measured data which was not evenly sequential (e.g., 2, 4, 7, 12, 15) was represented on an ordinal-level horizontal axis. Given the interval-ratio nature of the data, representation of raw-data in a scatter plot would have been more appropriate (with respect to how graphs are normatively constructed in science). All of the tables and graphs had structural flaws (not just labeling, etc) and, with few exceptions, these were not commented upon by the student teachers. For most of the high school student reports, this was significant because it affected the claims and implications which could be drawn from the reports. Overall, the feedback provided by the student teachers was particularly deficient in areas of data representation and, subsequently, the conclusions drawn from the data.

Conclusion

Together, these studies demonstrate that student-teachers have considerable difficulty in working with matters of scientific literacy, particularly in working with data in a fashion consistent with how science disciplines use it. This is not surprising, given that most pre service science teachers indicate that they themselves have never participated in anything other than Level l inquiry (question and method both provided, conclusions not provided), whereas reform documents generally call for high school students to have some experience with Level 3 (none of the question, method or conclusions are provided). This corresponds with information anecdotally shared amongst methods course instructors at conferences.

These studies are consistent with those that show that student teachers have difficulty interpreting data (Roth, McGinn & Bowen, 1998), conducting short-term inquiry studies (Bowen & Roth, 2005), long-term inquiry investigations (Windschitl, 2004), and discussing research studies, in which they have participated with scientists, in a manner consistent with discursive practices enacted by scientists (Bowen & Hembree, 2005). Consistent and prolonged interaction with scientists while they conduct their own studies do lead to some improvements in conducting inquiry (Lunsford et aI, 2007), although the variables examined are still low-level. Overall, it would appear that a BSc degree is insufficient to prepare student teachers to work with graphs and data in a canonical fashion, whether in regards to planning and conducting research, to analyzing and interpreting data, or to evaluating student work. This would clearly be a central issue in their ability to guide their own students in conducting inquiry-based investigations. Both their conduct and evaluation of inquiry investigations, including designing research activities, seems rooted in difficulties with working with data, whether in tables, graphs, or in statistical analysis.

Implications

From these studies, and from observations made during many years of watching student teachers design and conduct their own studies, two things seem to underlie these findings. First, student teachers do not seem to recognize that science studies, whether short or long term, usually focus on higher order interval-ratio variables from which statistical tests, correlation analysis, and predictive models can be constructed (such are commonly found in science publications; Roth, Bowen & McGinn, 1999), rather than focusing on the lower-order variables (nominal & ordinal) depicted in science textbooks (Roth, Bowen & McGinn, 1999; Bowen & Roth, 2002). Second, and related to the first, student teachers do not seem to recognize that particular types of variables (nominal, ordinal, interval-ratio) lend themselves to particular forms of analysis and graphical representation (for instance, interval-ratio data is more appropriately. represented by a scatter plot than by an ordinal line graph or bar chart).

This is clearly not an "ability" issue, since much research suggests that thirteen year olds, given an appropriate learning environment, can learn to conduct multi-variate studies with higher-order variables. Clearly, the problem has something to do with a lack of experience with appropriately scaffolded inquiry activities during their undergraduate science degrees. Thus I, along with others, have concluded that student teachers need to experience a variety of inquiry activities themselves to help them acquire this competency with data and inquiry practices.

My current direction in classroom practice (and research) involves better preparing student teachers to work with data by engaging them in short-term investigation activities. Given the tendency of teachers to delete details of content which they do not understand from the classroom lessons that they are designing (Hashweh, 1987), we should be little surprised if they similarly deleted practices (such as inquiry and data representation and interpretation) that they did not understand from their classroom ac1ivities. For this reason, I have my student teachers participate in activities that mirror the skill; and practices which the reform documents (and provincial curricula) direct them to develop in their own students. Some of the short-term activities they engage with are designed to develop an understanding of the rationale that underlies accepted research practices in science ("convincingness"). Others are sequentially designed activities, such that within each, the independent variable is modified from nominal to ordinal to interval-ratio. Concurrent with the short-term activities, they are also engaged in long-term studies which explore other aspects of inquiry, and engage in an extended series of journal readings about science education.

One lesson to be learned from the difficulty experienced in implementing classroom science inquiry activities in North America is that there is no point in designing a curriculum that varies greatly from the beliefs and practices of teachers; even if those practices are do-able by a thirteen year-old, that does not mean that the teachers will have an orientation favorable towards them being enacted. Clearly, there needs to be more research on how to best develop inquiry/data literacy in student teachers, so that they can best work with their own students. Also, as the research on beliefs suggests, there needs to be research on understanding the teacher-candidate orientations towards inquiry and pedagogy, as well as their understandings of the enacted practices of science, since these all determine the success of reform efforts.

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