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Student-teachers' Dialectically-developed Motivation for Promoting Student-led Science Projects

ABSTRACT

School science systems tend to emphasize teaching and learning about *achievements* of science (such as laws and theories), at the expense of providing students with opportunities to develop realistic conceptions about science and science inquiry and expertise they could use to conduct their own science inquiry projects. Among reasons for such an emphasis, teachers' lack of experiences with realistic science inquiry appears to be particularly problematic. Accordingly, we engaged student-teachers in a university-based course that attempted to balance instruction about science and science inquiry with student-teachers' own theorization about science and science inquiry. Qualitative data collected mainly from nine student-teachers in four focus groups indicate that these student-teachers' motivation for promoting student-led science inquiry projects in schools significantly increased by the end of the course. Analyses suggest that this outcome was influenced by: changes in their conceptions about the nature of science, changes in how they associated science inquiry with student learning, and the inductive-deductive dialectic immersion that was built into their pre-service methods course. Implications of these findings for science teacher education are explored in this paper.

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INTRODUCTION

*Give a man [sic] a fish and you will feed him for a day.
Teach him how to fish and you will feed him for a lifetime.*

Despite the long-standing advice in the above ancient Chinese saying, school science systems often place excessive emphasis on teaching and learning of 'products' — such as laws & theories — of science and technology, at the expense of helping students to improve their expertise for developing such knowledge and, as well, conceptions about the nature of processes and practices in the sciences. Among persistent problems is that many *teachers* have had insufficient opportunities to direct science inquiry projects or to gain an education about the nature of science. Accordingly, in this paper, we describe research into the efficacy of a particular pedagogical approach aimed at encouraging and enabling prospective secondary school science teachers to promote student-led science inquiry projects.

SCIENCE PROJECTS IN SCHOOL SCIENCE

Governments in various jurisdictions (e.g., DfEE, 1999; NRC, 1996) encourage school science teachers to help students develop *comprehensive* literacy. Although precise definitions are elusive, it can be helpful to think of such literacy in terms of achievement in Hodson's (1998) three broad domains; that is, for learning:

- i) 'Science'; i.e., *products* of science, including various laws and theories;
- ii) 'About Science'; e.g., characteristics of processes and products of science including, for example, that developing knowledge in science is non-linear, theory-dependent and often influenced by investigators' idiosyncracies, that certain cognitive 'skills,' such as variable control, are used, and that there are various positive and negative effects of technological products on individuals, societies and environments and ways to rectify such problems; and,
- iii) To 'Do Science'; i.e., expertise, confidence and motivation required to generate and communicate knowledge using methods of science and technology in unique problem-solving contexts.

In principle, such comprehensive literacy can promote positive outcomes for individuals, societies and environments.

[Insert Figure 1 about here]

Associated with discussions about *what* students should learn may be issues regarding *control* of their learning. Roger Lock (1990) has provided a theoretical framework for learning control in science education, as illustrated in Figure 1. This framework suggests that 'procedures' (e.g., activities, steps, etc.) that students follow can range across a continuum (the horizontal in Figure 1) from being fully teacher-directed (TD) through to being completely student-directed (SD). Conclusions that students draw, meanwhile, may range across a continuum from being completely 'closed-ended' (CE) — which tends to imply a pre-determined conclusion set by a teacher — through to being fully 'open-ended' (OE), which tends to imply no pre-set conclusions, leaving students to determine them. In principle, learning experiences can be located at various points around this framework. A lecture, for instance, often is highly TD and CE — as the teacher attempts to help students to learn particular aspects of 'Science,' for example. The 'success' of such instruction can vary, since learners are known to react differently to experiences, depending on their pre-instructional conceptions (e.g., Osborne & Wittrock, 1985). Such 'constructivist' theory suggests that ultimate 'control' of learning lies with learners, even

though the teacher might *aim* to control it. The teacher could, on the other hand, aim to encourage students to control their own learning. A science inquiry project, for example, could be largely SD and OE — as students, often in groups, determine purposes, methods and conclusions of an inquiry aimed at explaining some phenomenon of interest (e.g., effects of magnets on timepieces).

In school science (and, likely, in all subject areas), it is crucial for students to have opportunities to *produce* knowledge, as well as to consume it. Although it is essential that youth gain access to intellectual riches — such as products of science and technology — of their society (and of others), an exclusive (or nearly exclusive) emphasis on teaching pre-determined knowledge can be disempowering for learners. Given that all knowledge has embedded within it certain values, interests and power relations (Foucault, 1972), such an emphasis can, for example, be *indoctrinating* — in that transmitted knowledge may act as a set of implicit instructions for thought and action prescribed by those controlling schooling. Related to this, a consumption orientation also can inhibit students from developing meta-knowledge about knowledge-building processes and characteristics — along with expertise for knowledge building. In other words, as Collins and co-workers (2001) contend, an “overemphasis on ‘what we know’ at the expense of ‘how we know’ results in a science education which too often leaves students only able to justify their beliefs by reference to the teacher [or others who control scientific knowledge] as an authority” (p. 4). Such an education is undemocratic, minimizing citizens’ abilities to adequately evaluate and develop (scientific) knowledge. Therefore, in any democracy, it is essential that students “acquire knowledge by both studying external sources and engaging in complex activities that require them to *construct their own knowledge*” (Beane & Apple, 1995, pp. 15-16, emphasis added).

In school science, students can construct their own knowledge by conducting student-directed (SD), open-ended (OE) science projects (e.g., Roth & Bowen, 1995). Through control of various aspects of knowledge building (e.g., problem-setting, problem-solving and peer-persuasion), students may become more *questioning*, *creative* and *persuasive* and, perhaps critical to democratic life, able to *self-determine* their thoughts and actions. Related to such empowerment, students also may develop more realistic conceptions ‘About Science.’ Since most students are unlikely to work directly in science-related specialties, this sort of science education may enable them to become *citizen activists* (Roth & Désautels, 2002), able to promote and function effectively and responsibly in participatory democracies.

Despite the many arguments supporting student-controlled project work, learning experiences in school science classrooms tend to be highly teacher-directed and closed-ended (e.g., Hodson, 1998). Using various relatively teacher- and/or book-driven approaches, school science systems (e.g., textbook publishers, school and school district administrators, and teachers) tend to emphasize teaching and learning of ‘Science,’ at the expense of learning ‘About Science’ and to ‘Do Science’ (e.g., Eisenhart *et al.*, 1996). Even ‘science inquiry’ activities, which could be highly student-driven, can be orchestrated to ensure students develop widely-accepted conclusions of professional science. In a resource document promoting science inquiry, for example, the National Research Council (2000) states:

The term ‘inquiry’ is used in two different ways in the Standards. First, it refers to the abilities students should develop to be able to design and conduct scientific investigations and to the understandings they should gain about the nature of scientific inquiry. Second, it refers to the teaching and learning strategies that enable scientific concepts to be mastered through investigations. In this way, the Standards draw connections between learning science, learning to do science, and learning about science (p. xv).

In the National Science Education Standards (NRC, 1996), associating conceptual change with inquiry activities is very common — as reflected in the statement: “Inquiry ... refers to the activities of students

in which they develop knowledge and understandings of *scientific ideas*, as well as an understanding of how scientists study the natural world” (NRC, 1996, p. 23; emphasis added). As a consequence, prominent educators have made statements like: “Within a classroom, scientific inquiry involves student-centered projects, with students actively engaged in inquiry processes and meaning construction, *with teacher guidance*, to achieve meaningful understanding of scientifically accepted ideas targeted by the curriculum” (Schwartz *et al.*, 2004, p. 612, emphasis added). Therefore, efforts are still needed to shift the balance in science education away from a near-exclusive focus on knowledge consumption, giving students more opportunities to think and act independently (although, perhaps, collaboratively) — particularly through student-directed, open-ended science inquiry projects.

SCIENCE PROJECTS IN SCIENCE TEACHER EDUCATION

Among possible explanations for the relative dearth of student-controlled projects — such as concerns about equipment, space, student safety and demands to teach ‘Science’ — it is, arguably, particularly problematic that most teachers of science have had little experience with directing science projects (e.g., Roth *et al.*, 1998; Windschitl, 2003). Apparently, university science graduates (especially those holding B.Sc., rather than M.Sc., degrees) tend to have considerable difficulty with core inquiry practices, such as constructing and interpreting graphs using authentic data — which often are quite ‘messy,’ not following obvious patterns (e.g., Bowen & Roth, 2005). Without such expertise, teachers are likely to have difficulties facilitating and evaluating students’ science projects.

To help ensure teachers have opportunities to develop expertise relating to science inquiry, groups such as the National Research Council (2000) have recommended university-based teacher education programs more greatly prioritize science inquiry and the nature of science. In recent years, accordingly, there has been considerable success in university-based teacher education programs regarding future science teachers’ conceptions ‘About Science’ (e.g., Abd-El-Khalick & Lederman, 2000) and expertise to ‘Do Science’ (e.g., Windschitl, 2003). An ongoing problem associated with promotion of realistic student-controlled science projects, however, is that student-teachers tend not to have opportunities to implement them in their practice teaching sessions (e.g., Windschitl, 2003) and on into their teaching careers — often because of the aforementioned emphasis in school science systems on teaching ‘Science’ (e.g., Helms, 1998). Consequently, whatever motivation and confidence for teaching ‘About Science’ and to ‘Do Science’ that student-teachers may have developed during their university-based methods courses may dissipate or be suppressed in their work in schools. Student-teachers appear to need, therefore, experiences in their university-based teacher education programs that would help them to develop *deep* commitments to promotion of realistic science inquiry in schools.

In planning to help student-teachers to develop ‘deep’ commitments towards realistic science inquiry projects, it may be useful to conceive of depth in terms of ‘knowledge duality theory’ (e.g., Wenger, 1998). For deep learning, there must be close dialectical interactions between a person’s *participation* in the world and his/her representation(s) of it. It is not enough, for example, for learners to receive (e.g., via lectures) representations — such as written or oral statements about scientific laws. They also must have opportunities to *generate* their own representations through personal experiences (i.e., ‘participation’ in) with phenomena (e.g., reflection of light beams off of plane mirrors). Accordingly, teacher educators have engaged student-teachers in realistic student-directed, open-ended science inquiry projects during university-based teacher education methods courses and, related to those, reflections — through journaling, for example (e.g., Windschitl, 2003) — on the nature of science. In doing so, students would, presumably, be engaging in ‘inductive’ thinking — a process which, theoretically (recognizing, as discussed below, the theory-limited nature of observing), involves development of generalizations (e.g., regarding claims about science) from specific observations (e.g.,

from their own science inquiry projects). There is some merit to such an approach. Because science inquiry is highly idiosyncratic and situational (e.g., Latour, 1987), it may be that it is only through an individual's (idiosyncratic) immersion in a specific instance (situation) of science inquiry that realistic representations of it may emerge. On the other hand, there appears to be a practical dilemma associated with promotion of induction by itself. Assuming induction depends on conceptions that learners already have in their minds, it is unlikely that they will discover (induce) all possible conceptions about science or science inquiry. For this reason (at least), educators (e.g., Abd-El-Khalick & Lederman, 2000) have recommended more 'explicit' approaches; that is, strategies through which learners are purposefully and directly presented with particular (widely-accepted) claims about science and science inquiry. There appear to be inherent complexities with explicit approaches, however. Again turning to knowledge duality theory (e.g., Wenger, 1998), for such claims about science (*representations*) to have meaning for learners, they must be associated with learners' *participation* in relevant experiences. Learners must, therefore, have opportunities to evaluate such claims in meaningful contexts. This suggests, again, the importance of engaging student-teachers in realistic science inquiry activities — through which they may be able to evaluate claims about science made by teacher educators. Doing so involves *deduction*; that is, testing out generalizations (e.g., claims about science) through experiences with specific instances of science inquiry. However, although such deductive acts would allow learners to evaluate various claims about science (some of which would be explicitly presented to them), such tests may be biased — in the sense that claims about science presented to them may, in principle, not well-represent the nature of science. Perhaps due to the highly idiosyncratic and contextual nature of science, there are varying — often contentious — perspectives about it (e.g., Rudolph, 2000). Accordingly, it seems that university-based teacher educators need to promote realistic science inquiry by striking a fine balance between providing student-teachers with a relatively representative selection of claims about science — including conflicting ones — and enabling student-teachers to generate their own claims about science through realistic science inquiry activities (Bencze & Elshof, 2004). This paper examines experiences of student-teachers in conducting self-designed long-term inquiry projects in their science teaching methods course and their motivation for promoting independent inquiry activities with their future students.

RESEARCH & DEVELOPMENT

Research and Development Context

To understand more about encouraging student-teachers to promote student-directed, open-ended science inquiry projects in their future teaching, we designed a course that was intended to balance inductive and deductive thinking. To promote deduction, we provided student-teachers with a relatively representative selection of diverse claims about science and science inquiry and then encouraged them to evaluate these claims during realistic science inquiry activities directed by them. During their inquiries, we expected that, in addition to evaluating claims about science and science inquiry provided by us, they also might generate ('induce') their own claims about science inquiry. More specifically, the course featured the following main components relating to promotion of science inquiry:

- **Project Introduction:** On the first day of class, student-teachers were told that they were responsible for designing and conducting their own biology research projects. Their projects were to extend over two academic terms, lasting approximately 18 weeks. Although student-teachers were given considerable autonomy, they were required to have their focus-question 'approved' (by GMB) prior to beginning their investigation. This was to ensure student-teachers: i) chose an inquiry that

was optimally challenging, ii) did not violate ethical principles regarding work with Vertebrates, iii) met the pre-stated requirements of the project (quantifiable variables, not qualitative or categorical ones; variables that could be operationalized, given material resources at hand) and iv) engaged in reasonably equivalent tasks from a time-commitment perspective. In addition, student-teachers were restricted to using equipment that would normally be available in a 'typical' high school science lab. Overall, the following criteria, which had been successful earlier (Roth & Bowen, 1995), were used as a basis for establishing the inquiry environment:

- Students' work was to be characterized by investigating a problem that was ill-defined (allowing room for modification of the project as they proceeded).
- The project should allow students to experience uncertainties and ambiguities of drawing conclusions, as is typically found in professional science.
- The current knowledge state of the students in each project is used to locate the conceptual foundations of an acceptable project.
- Material and discursive practices and resources were to be shared and developed as part of communities of learners. 'Newcomers' of the community (often the students) could draw on expertise of more knowledgeable others (other students, teaching assistants, professors) or on any other suitable resource that could enhance their learning and engagement in their investigation.
- Expressing Pre-instructional Conceptions: Usually in concert with activities for *Learning New Conceptions* (refer below), student-teachers were encouraged to discuss with peers their views, perspectives, etc. relating to science inquiry and the nature of science. This is a fundamental strategy of constructivism-informed pedagogy (e.g., Osborne & Wittrock, 1985). In association with learning about inquiry strategies and practices, for example, student-teachers were asked to plan and conduct small-scale inquiries (refer below) and reflect on the nature of this work. Such reflective practice was, as well, built into the project as a whole — in the sense that student-teachers were to keep a logbook about their project and its data collection. There was no 'structure' required for this logbook, other than that they were asked to use both qualitative and quantitative descriptions. After the project, they were to submit a logbook with their formal report (which had no pre-specified format).
- Learning New Conceptions: Soon after student-teachers were asked to conduct a course-long project, they were provided with various activities and assignments intended to introduce them to a breadth of perspectives about science and science inquiry. For example, they were asked to evaluate some readings (i.e., Millar & Driver, 1987; Gallas, 1995, pp. 7-16; Gilbert *et al.*, 1982; Machamer, 1998; Yager, 1991) that dealt with various perspectives on learning, science and science inquiry. Student-teachers also had access to various 'traditional' sources of school science activities — including, for example, school science textbooks, lesson plan resources on websites and worksheets for guided-discovery laboratory activities. The professor rarely used direct instruction but, instead, provided activities in which student-teachers engaged in class discussions (or other activities) regarding these readings and issues pertinent to their own long-term investigations. They also participated in inquiry-based (teacher- and student-directed, but open-ended) science practice activities as part of the weekly methods class, frequently relating these to the course readings. To teach them about different orders of variables, student-teachers conducted small-scale inquiries involving rolling marbles down a ramp so that they pushed a (tipped-over) cup. In a later activity, they studied beetle investigatory behavior and velocity of movement in a new environment; an activity intended to facilitate discussions about possible adverse effects of investigative methods on phenomena being studied. Generally, this work was similar to an 'apprenticeship' approach described elsewhere (Bencze, 2000), in which control of procedures is

shared between instructor and students (although conclusions remain open-ended). It is also similar to lessons instructors provide regarding concepts-of-evidence (e.g., meaning and use of variable control), which have appeared to help students achieve success with inquiry activities (Van Rens *et al.*, 2004).

- Evaluating Available Conceptions: In concert with the ‘apprenticeship’ activities and course-long project, student-teachers were encouraged to evaluate claims about science and science inquiry made available to them. In addition to keeping track of their ideas in their logbook (refer above), a Web-based message board system also was provided to allow student-teachers to discuss problems and progress of their projects and the nature of science and science inquiry. Class time also was allotted twice each semester to allow presentation, defense and critique of their project work.

One of us (GMB) was the instructor for this course (and co-researcher), while the other (JLB) served as co-researcher. For both roles, we drew heavily on our previous experiences promoting student-led inquiry — in both our school teaching careers (JLB = 11 years; GMB = 5 years) and as university-based teacher education instructors (JLB = 9 years; GMB = 7 years). Much of our own motivation for promoting such project work stems, we believe, from having directed projects as part of our graduate biology degree programs (M.Sc.).

Data-gathering and Analyses

To determine and explain factors that may affect the extent to which the above approach motivated prospective secondary school science teachers to promote student-led science inquiry projects, research having both ‘rationalistic’ (i.e., pre-meditated) and ‘naturalistic’ (i.e., emergent) qualities (Guba & Lincoln, 1988) was conducted. It was *rationalistic* in that a main focus was on participants’ priorities and confidence for promoting realistic student-directed, open-ended science inquiry projects. However, given the evolving nature of educational research, we also expected that various unexpected research interests might emerge — thus also giving the research a significant *naturalistic* character. To accommodate this dualistic nature, the research involved use of qualitative data collection strategies, in an ethnographic tradition (e.g., Hammersley & Atkinson, 1990).

[Insert Table 1 about here]

Data were drawn from a university-based science teacher education methods class containing about 35 student-teachers, most of whom had degrees in science or engineering and were being prepared to work as secondary school science teachers. Student-teachers’ backgrounds ranged from having completed three full-year biology courses to having completed M.Sc. degrees. Nine student-teachers, distributed over four biology research project groups, also volunteered for more detailed study. Further information about these volunteers (including about the projects that they conducted for the course) is provided in Table 1. Data types collected included:

- Video Recordings of Science Project Work: Volunteering student-teachers were videotaped while participating in activities relating to science inquiry. These included in-class inquiry-based activities (e.g., experiments with bouncing balls) and student-teachers’ course-long biology research project. About seventeen hours of videotape were accumulated. The audio portions of these tapes were transcribed for later analysis.
- Evaluations of Propositions About Science: At the beginning and end of the course, student-teachers evaluated 20 statements that we believed (after separate, followed by collaborative, sorting) were representative of two main categories (10 statements each) — that is, *Rational-Realist* (RR) and *Natural-Antirealist* (NA) positions — within Loving’s (1991) *Scientific Theory*

Profile (refer to Figure 4). A selection of these statements is provided in Figure 2. All student-teachers wrote summary statements (approximately 200-250 words) about science after these discussions. Audiotape recordings of comments about these statements were collected from the nine student-teachers who volunteered for interviews (refer to Table 1).

[Insert Figure 2 about here]

- Semi-structured Interviews: Sixty-minute interviews were conducted with each of the nine volunteering student-teachers, at the beginning and end of the course. Guide questions explored student-teachers' claims about: i) science (e.g., 'What are scientists generally attempting to achieve?' and 'Describe and explain how scientists generally achieve their goals.')
- and ii) science education (e.g., 'Explain outcomes you consider most important in science education' and 'Explain teaching methods you would employ to achieve these major goals.'). To assist them in describing and defending their intended teaching practices, they were asked to discuss these with reference to various positions within Lock's (1990) control-of-learning framework, illustrated in Figure 1. During these interviews, student-teachers also were asked to judge merits of the stereotypical model of science processes in Figure 3 and explain any changes they would make to it. Each of these student-teachers also were asked to describe and defend — in a separate one-hour interview — their year-long research project.

[Insert Figure 3 about here]

- Samples of Project-based Assignments: All student-teachers enrolled in the methods course agreed to submit their project-related assignments for analysis, including: i) a survey about their perspectives and preferred science teaching methods, ii) inquiry-based activity sheets, iii) Interim (mid-term) and Final Research Reports and iv) written reflections (submitted electronically) on their projects, midway through and at the end of the course.

In terms of analysis, each of us first independently and repeatedly coded all data for relevant categories, and then refined, developed and related them to enable development of encompassing themes — using constant comparative methods, based on constructivist grounded theory (Charmaz, 2000). HyperResearch™ (version 2.0) qualitative analysis software was used to assist with coding and code analyses. Codes, categories and themes were then negotiated between us, based on the principle of “interpretive zone” as a “place where multiple viewpoints are held in dynamic tension as a group seeks to make sense of fieldwork issues and meanings” (Wasser & Bresler, 1996, p. 6). Our analyses of video data, grounded in interaction analysis (Jordan & Henderson, 1995), were based on the assumption that understanding and reasoning is observable in the form of socially structured and embodied activity (Garfinkel, 1967). Member checks with participants were then conducted to help ensure *trustworthiness* of claims, each of which was based on a minimum of three corroborating data sources (Guba, 1981).

RESULTS & DISCUSSION

Preamble

Data collected in this study indicated that the student-teachers increased their motivation towards encouraging their future students to conduct independent inquiry projects. In the two major sub-

sections below, details of student-teachers' new attitudes towards student-led science inquiries are provided, after which factors that may have contributed to their new priorities are discussed.

Emergent Change Agents

At the beginning of the course, most of the nine student-teachers who volunteered for close study indicated (e.g., through examples they used and their references to Figure 1) that they expected that they would mainly use teacher-directed and closed-ended teaching strategies in their future teaching. Strategies most-commonly mentioned included: teacher lectures, whole-class discussions (possibly using Socratic questioning), teacher demonstrations and guided lab activities. Two student-teachers indicated that they expected to use such TD/CE activities, despite the fact that one of them had conducted a 'science fair' project while in his ninth grade and that the other had worked as a government research assistant. Generally, they intended to teach in ways similar to how they had been taught. Matt (a kinesiology major, with a minor in biology), for example, described his previous experiences with classroom inquiries this way: "It was [like the teachers said,] 'Do this lab; here's how it's done. You do it. You [will] all get the same answers. Write up a report.' It wasn't like [they said,] 'Come up with anything yourself'" (Matt, Nov. 2002 Interview). Similarly, Ted provided a clear description of 'lab' activities that he and his colleagues had typically experienced:

Many of the laboratory experiments I had to complete in university were fairly straightforward. I was given a set of instructions (usually in a lab book) and told to record my results after conducting the experiment. The final stage was making sense of the data and regurgitating it in the form of a report. There was little independent thought and the projects basically followed a prescribed formula. I have to admit not having a clear, concise memory of the work involved in designing, implementing, and recording one's own experiment (Interim project report).

By the end of the course, all of the nine student-teachers interviewed indicated (e.g., with reference to Figure 1) that they would — to various extents — likely include in their teaching repertoires student-directed, open-ended science inquiry projects. Matt, for example, who had not previously conducted an independent science inquiry project, said:

I think that in a science class I want the kids to formulate their own problems and their own ideas. ... just give them the option of doing their own problems and ideas, rather than giving them specifics as we said before. I think children ... get enough education that's pushed on them, just as far as the limitations that they are going to learn. So why not have science, which is basically discovery, a class of discovery; different ideas and formulating different questions and researching? So why limit them to something that I am interested in or the textbook says is interesting? Why not give them their own opportunity to find out things that they would be interested in? I think that's what we learned from this whole project. Not even just this project, but class this year. ... Something that we [he and Karl] have no idea about ... we did by watching some crayfish crawling in a tank. I think we probably benefited more [than classmates with more extensive backgrounds in biology] because we had no idea what we were doing right from the beginning.

Even Gerry, who had worked as a field biologist (for about six years) for a government department and had assisted in numerous science projects, seemed to increase his enthusiasm for student-directed, open-ended science inquiry:

I think that this science project has definitely helped me to think about many ideas about science, and how I want to teach it. It was inconceivable to me 6 months ago that I would give a class such a directionless exercise. Now I think that this is exactly what I would do. ... Let them think, a dangerous thing for young folks to do, but put faith in their minds and they will affirm that faith.

Yes I think that this project may not work for all students, but let them try. If you need to guide some more than others, that's O.K., just let the project be their project (Gerry, Interim Project Report).

That the student-teachers interviewed indicated a new preference for promoting SD/OE inquiry projects in their teaching was somewhat surprising to us, given the level of frustration that they described experiencing while conducting their biology projects (Table 1). Ted, who had majored in Biology (although he had never conducted an independent science inquiry), stressed the importance of leaving students to their own resources in science knowledge building activities:

I think having the students fail would be a good idea. There is so much onus [in school science] on doing the perfect lab [simulated experiment] — when, in reality, it's nothing like that — because you are going to encounter failure, and not get the result desired, and you have to learn how to deal with that. In the aspect of inquiry, giving them the freedom to try things and allowing them to make mistakes, and then modifying their approach which is what they'll have to do (Feb. 2001 Interview).

Similarly, Dan said: "I think a student whose experiment works out perfectly will not get as much out of the activity as someone who had to struggle with the experiment. Being involved in the experiment and trying to figure out why it is not working and what can be done to improve it is important in order to learn valuable information" (Final interview).

The one major difference between the learning environments provided for student-teachers in the course studied here and those that they would provide for students was that they would provide more scaffolding of skills and attitudes for science project work — particularly for students with weaker science backgrounds. All but one of the student-teachers interviewed stated that their future teaching would include more 'apprenticeship' activities like the self-designed bouncing balls experiment (relating ball drop-to-bounce heights) that they experienced during their methods course. A typical comment about this was made by Karl: "I think some smaller experiments or other things in a classroom that allows [students] to learn how to possibly interpret data and show their data graphically or in some other way so that when it comes to their project, they have some idea" (Final interview).

Possible Motivational Factors

There may be several factors that could influence student-teachers' increased tendencies towards promotion of student-directed, open-ended science inquiry projects in their future teaching. Our analyses suggest that there were at least three general categories of influences, each of which is elaborated and defended below.

Seeing Science Inquiry in a New Light

[Insert Figure 4 about here]

A major factor contributing to student-teachers' newly-developed orientation towards promoting SD/OE science inquiry projects seemed to be an apparent shift in their views about the nature of science. Evidence suggests that most (8 of 9) of the student-teachers reduced their support for Rationalist-Realist positions on Loving's (1991) Scientific Theory Profile (STP) while increasing their support for Naturalist-Antirealist positions (refer to Figure 4). In terms of the Rationalist-Naturalist continuum of the STP, for example, all nine student-teachers initially indicated that they felt that the model of science processes provided in Figure 3 properly represents professional science practices.

Matt said, for instance, that the model “represents the method of scientific discovery that we were taught throughout high school and some university courses.” After the course, however, Matt (similar to most of the others’ interviewed) discussed the model this way: “I don’t know if there is a specific map to science. You know, you start here [pointing to “Observed Variables” in Figure 3] then you go here. I think it is very similar to this, but, in science, there’s different variables, different limitations where they have to back-track or do different things or repeat steps” (Final Interview). Similarly, Matt indicated that he felt that he no longer supported statements about science like: “The best scientists follow the steps of the scientific method.” About such statements, he said: “My previous views of science were, like most [student-teachers], based on ideas of the scientific method. Science was [thought to be] conducted in a manner using distinct steps, and facts were developed based on these procedures. ... Today, science is often influenced by money and altered to generate a desired outcome.” In agreement, Tania said:

The most noticeable change in my thoughts occurred in how I thought the scientific method was used. I think that I had a very rigid structure in regards to the scientific method. I now think that it is a very fluid process, and is heavily influenced by social interactions among scientists. This occurred not only in my group [project] but also on a classroom scale. We tried ideas out on each other and other students helped us perfect our method. I think that this is how science operates, it is not a static entity. Community is very important. I think that this is important to project on students, because I think that it is a common misconception. I have tried and will continue to use social interactions in the process of science (Final Project Report).

Regarding the Realist-Antirealist continuum of Loving’s (1991) STP, most (7 of 9) of the student-teachers we interviewed indicated that they had come to question the absolute certainty of scientific knowledge — due, particularly, to limits they now perceived about the extent to which humans can know and control all variables in inquiries. This is clearly evident, for example, in Daniela’s description of problems encountered in their project:

Every time the group meets to talk about our experiment, we always come up with unanswered questions. Firstly, how are we supposed to know what concentrations of salt to use. What if we discover that our concentration of 0.05% kills the plants in plot B? Then, we will have no good, useful results to explain. On the other hand, what if the concentration of salt at 0.15% is too concentrated even for the plants in plot A? Now we’ll have dead plants from plot A and B. By the time the plants die, it will be too late to do anything about it. So many things can go wrong and it is hard to try to prevent these things from happening. Secondly, as mentioned in the Observations section, if we identify many different types of plants, it’ll be four times that many that we’ll have to grow. Not only will this be costly and time consuming, but where are all these plants going to go so they all receive the same types of conditions (ie. sunlight, wind). Lastly, just because a plant 5m from the road doesn’t do well in the salt conditions, doesn’t necessarily mean it is from the salt. Other factors can come into play here like less wind than there would be if the plant was along the road (cars and trucks speeding by on the road). Also, what does it mean if a plant from along the road doesn’t do well in the salty conditions we grow it in. Or just because the plants from plot A do better in the salty conditions, does it mean the plants need a salty environment or did they just adapt to it? (Final Project Report).

Apparently due to such experiences, the student-teachers we interviewed seemed to develop ‘instrumentalist’ perspectives about scientific knowledge; that is, a view that ‘truth’ can best be equated with consensual knowledge that seems useful in various applications (Eflin *et al.*, 1999). For example, Karl (Matt’s project partner) said: “I have ... discovered that most scientific procedures don’t usually achieve the goals they set forth to do [sic]. They simply are useful due to the unpredictable and accidental discoveries that result from their application.”

As a result of student-teachers' apparent development of instrumentalist positions about knowledge, they appeared to become less interested in ensuring students develop 'the right' conclusions from their inquiries. Matt reflected this perspective well when he said: "I think that it's important for students to know that you don't always have to make them [predictions for inquiries] work. And if we were still the same way now as when we first walked into the [methods] classroom, these results would have been [adjusted to appear] perfect. No matter what they were, they weren't [perfect]. They would have come out in the end on a piece of paper and they would have been perfect because we would have fudged them" (Interim Interview). Consequently, these student-teachers appeared to be most interested in having students focus on thought processes in dealing with data. Daniela, said, for example: "As a result of this project, I realized that the final result is not the most important thing when conducting an experiment or study; it is the *journey* and problems encountered that matter the most" (emphasis added).

Relating Science Inquiry to Learning

As the student-teachers we studied developed (apparently) more Naturalist-Antirealist views about science, several of them (5 of 9) also indicated that they developed some motivation for promoting student-led projects because of parallels they noted between student learning and science inquiry. Some felt, for example, that the idiosyncratic and situational nature of science inquiry would be appropriate for addressing the inherent diversity that is found in science classrooms:

I think the most important thing I learned doing this project is the distinction between the *same* and *equal*. ... [Due to her lack of biology education, she said:] I always sort of felt that [her project] wasn't 'good enough.' ... But having feedback and support [from GMB] altered my abilities in science (and I think this is true in any classroom), made me feel more motivated about what I was trying to accomplish. Although the support was not the same for every member of the class, we were all treated equally and expected to reach the same goal; understanding inquiry learning. I don't think that anyone who did this project (whether they succeeded or failed with their results), learned any more or any less than I did by doing it (Janine, Final Project Report).

Others spoke strongly about the sense of *ownership* they detected in conducting their own project (which may be true for practicing scientists) and that this would also be true for students:

I believe that [students he was mentoring were enthusiastic about project work] because they have chosen their project entirely and enjoy working on it. When those students are asked to think of something for the next session, or they are asked to complete a task for the next day, they do it! They are doing this extra work because they enjoy it, but more than that, they have taken ownership of the project. What they are learning from this process is being internalized (Gerry, Interim Project Report).

Finally, at least one student-teacher interviewed discussed educational and epistemological parallels regarding relationships between theory and evidence:

... with interpreting results, I think by teaching them to make connections from results to reason or to their interpretation of reason, that I think when you do other things in the classroom, it will help them connect the theories to the different experiments that you might do, that would be on a smaller scale to learn better or to be able to visualize science better and what's happening in the classroom (Karl, Interim Interview).

An Inductive-Deductive Dialectic Immersion

As predicted above (“Science Projects in Science Teacher Education”), data collected here suggest that an inductive-deductive dialectic immersion in realistic contexts of knowledge building (i.e., a long-term collaborative biology project) contributed to student-teachers’ apparent commitment to promotion of realistic science inquiry projects in their future teaching. In terms of inductive thinking, all of the student-teachers reported that their projects were non-linear, for example, including in terms of changing goals and purposes, methods, and conclusions — which they attributed to such factors as *group disagreements about topics*, *difficulties determining appropriate measurement techniques*, and *new theoretical and methodological insights after methods had been determined*. Barriers to progress were, for some student-teachers, so intense they felt compelled to abandon their original project goal in favor of another. A group that had intended to sample water above and below a pulp mill, assuming pollution from the mill would reduce biomass, found the *opposite*. Not knowing how to get the water tested for pollutants, etc., they switched topics: “Generally, there were too many variables that we didn’t know how to deal with and didn’t know anything about, and that is one of the biggest reasons we abandoned our first experiment” (Janine, Final Project Report). Ted had similar frustrations, but it did not appear to dampen his motivation for promotion of such problematic experiences:

We had to take into consideration the equipment available, the approximate time to invest, the resources accessible (background information, etc.) and the basic scientific principles (creation of a scatter plot). After some time, a procedure was settled upon and the experiment could move forward. Students have a lot to consider when conducting an experiment of their own. If they fail to think carefully on the subject then they could run into serious difficulties later on. ... Doing a research project requires a lot of time, thought and dedication. I am beginning to have a clearer understanding of the process my students will eventually go through. When I decide to assign an independent research task I will have a much more accurate perspective of what they are going to have to do. ... There are many variables and obstacles that a person must encounter when doing something like this. I believe it would be most beneficial for students to have to experience science in this manner as it fosters critical and independent thinking skills (Final Project Report).

At the same time, several (6 of 9) of the student-teachers specifically mentioned *deductive* support for their new motivation to promote student-led science inquiry. After reiterating frustrations inherent to her project work, for example, Tania explicitly related them to a reading provided in the biology teacher education methods course:

Above all else, the one thing that I learned was that science is filled with minute difficulties, and subjectivity. Every step was a battle over the variables that effected our project, often a losing battle. We made decisions that effected the outcome of our experiment; this is the same in scientific world. The tiniest of decisions effected our method, results, and conclusions. Science is not as cut and dry as I had previously thought that it was. In addition, science is a lot more creative than I previously had thought. We had to come up with some pretty interesting ways to make our project effective. Every single step of the project was a creative endeavor. It began with coming up with project ideas, then a method, how to best observe, how to perform the soil samples, and the list continues. I do not think that this is something that is recognized or fostered in the science classroom enough. In many ways, my experience mirrored some of the suggestions Gallas (1995) made in her [chapter], ‘What is Science.’ She talked about getting the students to mimic the world of scientists so they can begin to understand how science is made. She also emphasized the importance of community and getting the students to talk about science. I think that her most lasting point was that in school science we only see the final product of the scientific journey. Rather, she suggests we let the students’ experience and see behind the ‘mess’ that is science. I think this is my experience of the project.

Janine also had confirmation of ideas about science from Gallas' (1995) chapter, but also noted that the biology inquiry allowed her to induce some conclusions:

As Gallas [1995] talks about in her [chapter], instilling a sense of wonder and curiosity in children is a far more effective approach to science than rote memorization and completing text book labs. Using children's inherent curiosity about things is a really great way to get them to think about why and how things are the way they are. This type of project [i.e., the SD/OE biology project] relates well to the article because of the amount of thinking and consideration required. The de-emphasis on success of a project, and the emphasis on questioning and finding out how to answer questions, or developing new questions is important for students to understand how the scientific process operates. Gallas discusses how students come to school eager to engage in scientific activities, but often teachers can't meet that need because they don't understand the process of real science. Engaging in an activity such as this while learning to be a teacher is an invaluable asset to us as we now understand a little bit more of the process of science and are able to introduce this attitude of curiosity that Gallas advocates in her [chapter]. ... I kind of think about this project like a movie with a surprise ending. Throughout the whole thing there are clues as to what will happen, you know that something is up, you try like mad without success to figure out what it is, but when the movie is over there is a big sense of 'OHHHH!!!!, that's what it was about'. I really don't think that things could be changed much to make this experience any more valuable. Just tell next year's students 'Trust me, it's worth it.' Although they might not believe you for an entire year, they will during the last week (Janine, Final Project Report).

SUMMARY & CONCLUSIONS

Evidence from this study suggest that elements of a university-based science teacher education methods course led student-teachers to become motivated to include student-directed (SD), open-ended (OE) science project work in their future teaching. As argued above, although beginning teachers may still face opposition from colleagues, their enthusiasm may encourage them to promote student-controlled science inquiry projects. Doing so could help students to develop realistic conceptions 'about science' and expertise for 'doing science' — in addition to learning 'science.' With such comprehensive literacy, students could function effectively in societies greatly affected by processes and products of science and technology.

University-based teacher educators wanting to encourage student-teachers to promote realistic student-directed, open-ended science projects may benefit from the approach described in this report. The approach involves engaging student-teachers in *inductive* and *deductive* thinking (dialectically) relating to science inquiry projects. To promote deductive thinking, student-teachers were explicitly presented with various perspectives about science and science inquiry (e.g., through readings and through small-scale practice inquiry activities) and, then, encouraged to evaluate (deduce) these perspectives and practices through course-long biology research projects under their control. At the same time, they could engage in inductive thinking, as they developed claims about science and science inquiry through experiences with their inquiry projects.

Encouraging student-teachers to develop new perspectives about science and science education by facilitating cycles of inductive and deductive thinking in relation to science inquiry projects has pedagogical and philosophical support. Neither inductive nor deductive thinking alone is appropriate. From fields of science studies (e.g., Latour, 1987), it is apparent that science practices are highly idiosyncratic and situational (dependent on myriad, often interacting, variables). Accordingly, it seems logical to encourage students to *induce* ideas about science through engagement in particular instances of science in the making (e.g., science projects). In practice, however, learners have difficulties

‘discovering’ abstractions (e.g., conceptions about science) about which they do not have prior notions (e.g., Osborne & Wittrock, 1985). This suggests, therefore, that it is necessary to provide learners with conceptions (in this case, about science and science inquiry). In doing so, we would be promoting *hypothetico-deductive* thinking. Students could, in other words, test conceptions about science available to them (including those given to them) through interaction with specific cases of science in action (as with the biology projects described here). Such thinking has been said to be common in the sciences (e.g., Lawson, 2005), although it is important to acknowledge the likely strong social character of such thinking (e.g., Latour, 1987). Through such socially-mediated hypothetico-deductive thinking, moreover, conceptions about science developed and/or verified by learners would be ‘deep’ — since, based on knowledge duality theory (e.g., Wenger, 1998), there would be close associations between learners’ representations of science inquiries and their participation in them.

Through the teacher-education approach described above, it was apparent that the nine student-teachers we studied most closely shifted their perspectives about science from those more congruent with Rationalist-Realist positions to those aligning more greatly with Naturalist-Antirealist positions on Loving’s (1991) *Scientific Theory Profile*. For example, they came to view science inquiry as a much more idiosyncratic and situational process than they had previously thought. This change in perspective, in turn, seemed to be associated with these student-teachers’ increased motivation for promoting student-directed, open-ended science inquiry projects in their future teaching. Others’ studies of teachers’ views about science and science teaching practices resulted in similar conclusions (e.g., Bencze *et al.*, 2006; Kang & Wallace, 2005). In this study, moreover, student-teachers also concluded that Naturalist-Antirealist perspectives about science were congruent with how they viewed *learning* — as an idiosyncratic and contextual process. This study lends further support, therefore, to the idea that teachers most likely to promote student-directed, open-ended science inquiry projects are also likely to adhere to Naturalist-Antirealist views about science, and that that result may be influenced by teachers’ views of learning. The opposite also appears to be true; that is, that teachers adhering to more Rationalist-Realist perspectives about science (and learning) are less likely to promote student-led inquiries. In conclusion, therefore, teacher educators wanting to encourage student-teachers to promote student-directed, open-ended science inquiry projects in their future teaching might find that this can be accomplished by engaging student-teachers in an inductive-deductive dialectic experience involving student-led projects and instruction in a spectrum of views about science. Under conditions similar to those described here, they might also find that, despite exposing student-teachers to various positions around Loving’s (1991) *Scientific Theory Profile*, they may accommodate more Naturalist-Antirealist views — and it is this change that is particularly influential in their motivation to promote student-led inquiries in their future teaching.

REFERENCES

- Abd-El-Khalick, F. & Lederman, N.G. (2000). Improving science teachers’ conceptions of nature of science: A critical review of the literature. *International Journal of Science Education*, 22(7), 665-701.
- Beane, J. A. & Apple, M. W. (1995). The case for democratic schools. In M. W. Apple & J. A. Beane (Eds.), *Democratic schools* (pp.1-25). Alexandria, VA: ASCD.
- Bencze, J. L. (2000). Procedural apprenticeship in school science: Constructivist enabling of connoisseurship. *Science Education*, 84(6), 727-739.
- Bencze, L. & Elshof, L. (2004). Science teachers as metascientists: An inductive-deductive dialectic immersion in northern alpine field ecology. *International Journal of Science Education*, 26(12), 1507-1526.

- Bencze, L., Bowen, M., & Alsop, S. (2006). Teachers' tendencies to promote student-led science projects: Associations with their views about science. *Science Education*, 90(3), 400-419.
- Bowen, G. M., & Roth, W.-M. (2005). Data and graph interpretation practices among pre-service science teachers. *Journal of Research in Science Teaching*, 42(10), 1063-1088.
- Charmaz, K. (2000). Grounded theory: Objectivist and constructivist methods. In N. K. Denzin & Y. S. Lincoln (Eds.), *Handbook of qualitative research* (pp. 509-535). Thousand Oaks, CA: Sage.
- Collins, S., Osborne, J., Ratcliffe, M., Millar, R. & Duschl, R. (2001). What 'ideas-about-science' should be taught in school science? A Delphi study of the expert community. Paper presented at the annual conference of the *American Educational Research Association*, April 10-14, 2001, Seattle, WA.
- Department for Education and Employment [DfEE] (1999). *Science: The national curriculum for England*. London: HMSO.
- Eflin, J. T., Glennan, S. & Reisch, G. (1999). The nature of science: A perspective from the philosophy of science. *Journal of Research in Science Teaching*, 36(1), 107-116.
- Eisenhart, M., Finkel, E. & Marion, S. F. (1996). Creating the conditions for scientific literacy: A re-examination. *American Educational Research Journal*, 33(2), 261-295.
- Foucault, M. (1972). *The archaeology of knowledge and the discourse on language* (translated by A. M. Sheridan Smith). New York: Pantheon.
- Gallas, K. (1995). *Talking their way into science: Hearing children's questions and theories, responding with curricula*. New York: Teachers College Press.
- Garfinkel, H. (1967). *Studies in ethnomethodology*. Engelwood Cliffs, NJ: Prentice-Hall.
- Gilbert, J. K., Osborne, R. J. & Fensham, P. J. (1982). Children's science and its consequences for teaching. *Science Education*, 66(4), 623-633.
- Guba, E. G. (1981). Criteria for assessing the trustworthiness of naturalistic inquiries. *Educational Communication and Technology Journal*, 29(2), 75-91.
- Guba, E. G. & Lincoln, Y. S. (1988). Naturalistic and rationalistic enquiry. In J. P. Keeves (Ed.), *Educational research, methodology and measurement: An international handbook* (pp. 81-85). London: Pergamon Press.
- Hammersley, M. & Atkinson, P. (1990). *Ethnographic principles in practice*. London: Routledge.
- Helms, J. V. (1998). Science—and me: Subject matter and identity in secondary school science teachers. *Journal of Research in Science Teaching*, 35(7), 811-834.
- Hodson, D. (1998). *Teaching and learning science: Towards a personalized approach*. Buckingham, UK: Open University Press.
- Jordan, B. & Henderson, A. (1995). Interaction analysis: Foundations and practice. *The Journal of the Learning Sciences*, 4, 39-103.
- Kang, N.-H. & Wallace, C. S. (2005). Secondary science teachers' use of laboratory activities: Linking epistemological beliefs, goals, and practices. *Science Education*, 89(1), 140-165.
- Latour, B. (1987). *Science in action: How to follow scientists and engineers through society*. Cambridge, MA: Harvard University Press.
- Lawson, A. E. (2005). What is the role of induction and deduction in reasoning and scientific inquiry? *Journal of Research in Science Teaching*, 42(6), 716-740.
- Lock, R. (1990). Open-ended, problem-solving investigations: What do we mean and how can we use them? *School Science Review*, 71(256), 63-72.
- Loving, C. C. (1991). The Scientific Theory Profile: A philosophy of science model for science teachers. *Journal of Research in Science Teaching*, 28(9), 823-38.
- Machamer, P. (1998). Philosophy of science: An overview for educators. *Science & Education*, 7(1), 1-11.

- Millar, R. & Driver, R. (1987). Beyond processes. *Studies in Science Education*, 14, 33-62.
- National Research Council [NRC] (1996). *National science education standards*. Washington: National Academy Press.
- National Research Council (2000). *Inquiry and the national science education standards: A guide for teaching and learning*. Washington, DC: National Academic Press.
- Osborne, R. & Wittrock, M. (1985). The Generative Learning Model and its implications for science education. *Studies in Science Education*, 12, 59-87.
- Roth, W.-M. & Bowen, G. M. (1995). Knowing and interacting: A study of culture, practice, and resources in grade 8 open-inquiry science classroom guided by a cognitive apprenticeship metaphor. *Cognition and Instruction*, 13(1), 73-128.
- Roth, W.-M., & Désautels, J. (Eds.) (2002). *Science education as/for sociopolitical action*. New York: Peter Lang.
- Roth, W.-M., McGinn, M. & Bowen, M. (1998). How prepared are pre-service teachers to teach science inquiry?: Levels of performance in scientific representation practices. *Journal of Science Teacher Education*, 9(1), 25-48.
- Rudolph, J. L. (2000). Reconsidering the 'nature of science' as a curriculum component. *Curriculum Studies*, 32(3), 403-419.
- Schwartz, R. S., Lederman, N. G. & Crawford, B. A. (2004). Developing views of nature of science in an authentic context: An explicit approach to bridging the gap between nature of science and scientific inquiry. *Science Education*, 88(4), 610-645.
- Van Rens, L., Pilot, A., & Van Dijk, H. (2004). Enhancement of quality in chemical inquiry by pre-university students. *International Journal of Science and Mathematics Education*, 2(4), 493-509.
- Wasser, J. D. & Bresler L. (1996). Working in the interpretive zone: Conceptualizing collaboration in qualitative research teams. *Educational Researcher*, 25(5), 5-15.
- Wenger, E. (1998). *Communities of practice: Learning, meaning, and identity*. New York: Cambridge University Press.
- Windschitl, M. (2003). Inquiry projects in science teacher education: What can investigative experiences reveal about teacher thinking and eventual classroom practice? *Science Education*, 87(1), 112-143.
- Yager, R. (1991). The constructivist learning model, towards real reform in science education. *The Science Teacher*, 58(6), 52-57.
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