Learning to Teach Science as Inquiry in Higher Education: A Course in Innovative Teaching

Barbara A. Crawford

Cornell University
Ithaca, New York USA

In this paper I describe the nature of a new university course on reformed-based pedagogy offered at a research-intensive university in the United States, and report on its influence on prospective college teachers' views of teaching science. The course, Innovative Teaching in the Sciences (ITS) targets science doctoral students who plan to teach in higher education or extension work, and is designed to shift the focus from primarily transmitting science facts through large lectures, to engaging students in active learning, inquiry, and nature of science, aspects of reformed-based science teaching as articulated in reform documents for K-12 education in the U.S. The research design used an interpretive, qualitative approach (Creswell, 1998; Miles & Huberman, 1994) and involved gathering multiple data sources, including course products and responses to a Pre-course questionnaire. Students began the course with naïve views of what it means to teach science as inquiry and developed more robust philosophies of teaching science. In final espoused statements all students showed movement towards student-centered and inquiry-based approaches. The findings of this study add to the limited research on inquiry-based teaching at the college level.

Email author: bac45@cornell.edu

Address:
Department of Education
407 Kennedy Hall
Cornell University
Ithaca, New York 14853
U.S.A.

A paper presented in a Symposium at the European Science Education Research Association International Conference (ESERA) in Istanbul, Turkey August 31-Sept 4, 2009

Problem

Most undergraduate level science college courses in the U.S. are traditionally taught through large lectures (Shipman, 2004). A college science course syllabus often covers a vast array of topics, with few, if any, laboratory experiences. In course evaluations many students report poor teaching. There is evidence that students do not necessarily develop understandings of science concepts through lecture-based classes, when there is little student input or engagement (see NRC, 1996, 2000). To address this situation the United States has published guidelines for changing the way science is taught in higher education (National Science Board, 1996). However, it is difficult to overcome the inertia of large lecture formats, especially in poor economic times.

Yet, some changes are apparently taking place, in the way science is taught in undergraduate level courses (Shipman, 2002). And, there is a gathering movement towards using new ways to teach science at the university level. Although there appears to be interest in inquiry-based instructional practice, there is little empirical evidence that things have changed in the ways professors generally teach undergraduate science classes. Recently, there have been a few studies published specifically focused on inquiry teaching in higher education. One study by Gess-Newsome, Sutherland, Johnston, & Woodbury (2003) researched three college professors, as they designed and taught inquiry-based classes. The researchers used teachers' personal practical theories and conceptual change as a framework. The reality is that many college professors have a narrow view of inquiry-based instruction, and believe this kind of instruction takes too much time to warrant changing from direct teaching and large lecture format (Brown, Abell, Demir, & Schmidt (2006).

I am a science teacher educator whose primary focus is clearly centered on preparing secondary level (U.S. ages 11-18) science teachers to teach in reformed-based ways, and in supporting in-service teachers in engaging students in gaining deep understanding of key science concepts, and in understanding what science is, and what science is not. My main goals include changing the way science is taught in most science classrooms. Students in my methods classes are generally preparing to teach biology, physics, chemistry, and earth science at the pre-college level, usually in public schools. My prospective science teachers often report to me that they have inadequate educational experiences in their introductory undergraduate science content courses, where they are often forced to memorize huge volumes of information, and they become frustrated with multiple-choice examinations. Recently, I designed an elective graduate level course for doctoral students, who are interested in teaching in higher education. The target audience includes graduate students engaged in high-level science research projects at a large top-tier research institution. Instead of focusing this new course on general pedagogy at the college level and giving it the generic title of College Teaching, I aimed to address the state of affairs that many university science professors use a traditional lecture-based approach, rather than reformed-based inquiry approaches. The new course titled. Innovative Teaching in the Sciences (ITS), was designed to shift the focus from transmitting science facts through large lectures, to engaging students in active learning, through using inquiry-based approaches (i.e. Schwab,1962), and learning about nature of science and use of critical thinking-- aspects of reformed-based science teaching as articulated in documents aimed at K-12 level teaching (Anderson, 2002; NRC, 2000). Conscious effort was made to model inquiry teaching methods as part of the course.

This paper is the result of conversations with colleagues at a national conference on research in science teaching in the U.S., a few years ago. By coincidence we discovered we were all exploring how to support prospective college instructors in teaching science, not as a litany of facts, but as inquiry and by understanding nature of science. We agreed to examine the influence of our courses on students' views of teaching science.

In this paper I will describe the rationale for the design of this university level course in teaching and learning and its influence on prospective college instructors' views of teaching. The course combined reading empirical research on learning and teaching science, class discussions on inquiry and nature of science, strategies for teaching, alternative assessments, learning technologies, and opportunity for lesson design and peer teaching. A central aspect of the course is the development of a personal philosophy of teaching and learning science, with an eye towards innovative teaching.

Theoretical Framework

The theoretical framework of this study includes constructivist perspectives of learning and teaching; the view that children and adults learn through engaging in experiences and structuring their understandings based on these experiences (Brown, 1994; Cobb, 1994; Driver, Asoko, Leach, Mortimer, & Scott, 1994). The view that learners need be active in thinking processes in order to develop their own robust understandings, is embodied in constructivist views of learning. A social constructivist view of learning involves the negotiation of ideas among people in conversation and debate (Brown, et al, 1989; Solomon, 1989, 1993; Vygotsky, 1978; Wood, Cobb, & Yackel, 1992) that also frames both the design of the course, and the design of the study and analyses focused on collaboration and negotiating understandings (Crawford, Krajcik, & Marx, 1999).

Research Design and Data Sources

The research design used an interpretive, qualitative approach (Creswell, 1998; Miles & Huberman, 1994) and involved gathering multiple data sources, involving course products and responses to a questionnaire. I was interested in my students' initial goals, the development of their philosophies of teaching and learning, and changes, if any, in their philosophies and their views of inquiry, nature of science and inquiry-based pedagogy.

None of the data were gathered external to the normal course requirements. One data source was the Pre-course Questionnaire (see Appendix A). Students' goals and educational backgrounds were collected on-line, immediately after the first class session. Also, questions targeted prior research experiences and initial views of inquiry and nature of science, as well as central aspects of their current philosophies of teaching. An important data source was each student's espoused philosophy statement, written in the early part of the course and revised towards the end of the course (see Appendix B). For the purposes of this study I developed a coding/scoring guide based on the essential features of inquiry, and aspects of nature of science related to teaching science found in the literature (see Appendix C). I coded these philosophy statements and determined pre and post numerical scores, in addition to qualitatively analyzing the writings as a whole. Course work used as data included lesson plans designed and carried out for their peer teaching episodes as a normal part of the course. Lesson plans were viewed for features of inquiry and nature of science. In designing their lessons each students selected a science concept or principle related to his or her research area.

The participants in this study were a sample of the twenty students who formally enrolled in the course the second year. Some of the students were education doctoral students who had taken other education courses. I did not include their work in the study, as I was interested in how prospective college teachers with little prior experience in education coursework might change their views as the result of taking a single course. The study sample consisted of those students who took the course for college credit and who intended to go on to teach in higher education; and who did not have prior education coursework. My university has a policy that allows students to "shop for courses" the first three weeks of the semester. Although I expected at the most, ten students would register for the course (this is an elective graduate seminar style course), more than 25 students showed up for the first class. Interestingly, some of my students confessed their major professor had cautioned them that the course would take precious time away from their laboratory research. Yet, they came. Some of the students chose to audit the class, fearing the assignments might take too much time away from their research; a few were on the job market interviewing for positions as post docs or faculty in other universities. One student dropped the class following the third class session, having never officially enrolled in the course. In this case, dropping the course may have resulted in part from my clear emphasis during the first class sessions a view of learning and teaching science quite foreign to this particular physics student. During discussions, this particular student vehemently argued with other students about what science is, and struggled with understanding the point of the readings in learning how to teach science. A third student, halfway through the semester, confessed he would not have time to complete all the assignments; he would be willing to take an F (failing grade), if he could just continue to come to the class discussions. He found these discussions valuable, but he felt swamped with his own laboratory work. These aforementioned students' course products and questionnaires were not included in the data set for analyses.

My rationale for using designed lesson plans as evidence of students' intentions and views of teaching science as inquiry stems from the assumption that these students have more freedom in topic selection and using innovative approaches, as compared with student teachers in a pre-college teacher preparation program. Prospective college instructors do not have to satisfy school district guidelines or the demands of cooperating teachers. Thus, I claim, it is appropriate to infer from their designed lesson plans, the nature of these prospective college instructors' views of teaching and learning science.

Research questions include the following:

1) *What are prospective college instructors' emerging philosophies of teaching, and how do they change, if at all, during the course?*

2) *What is the evidence that prospective college instructors develop an understanding of teaching science as inquiry?*

The Nature of the ITS Course

The goal of the ITS course is to prepare college science instructors to facilitate the intellectual growth of their students as critical thinkers, while providing those students with a robust personal understanding of the nature of science; using innovative, student-centered, inquiry-based instruction as a substitute or supplement to traditional style instruction. The course description states:

> This course combines the research on learning and teaching science, with the pedagogy and practical applications for teaching science at the college level, as well as extension and in informal settings. The instructor emphasizes how to design effective learning environments that actively involve students in critical thinking. Innovative Teaching in the Sciences addresses a variety of instructional approaches, including problem-based, collaborative learning, model-based, community-based, and the use of authentic contexts. Examples are grounded in practice. Readings focus on the empirical research related to this kind of teaching, including issues of gender and underrepresented populations in science and math

and engineering, and highlights the benefits of using inquiry-based teaching approaches, as well as challenges and pitfalls. Students are given real opportunity to apply their knowledge of designing inquiry-based instruction, and critique inquiry-based instruction and assessments in their own field. One of the key components of the course involves the design and teaching of a lesson with peer feedback.

My goal was to enable prospective college instructors to develop instructional plans and design learning environments that support in-depth learning of key concepts and an understanding of the nature of science through inquiry (Schwartz & Crawford, 2004.) One central goal of the course was that each student would develop lessons, which would reflect reform-based views of inquiry-based teaching and nature of science.

In one of the key assignments students are asked to do the following:

> **Design of Inquiry-based Instruction and Peer Teaching:**
> You will identify a set of concepts or principles in your discipline, formulate a *Driving Question,* and design an innovative instructional plan (lessons/labs) for use in your particular teaching situation. You will use the principles of inquiry-based instruction gained from readings and class discussions, and 1) present an overview of your instructional design to the class; and 2) teach a segment of a lesson to your peers for feedback.

The course syllabus lists questions for each session, not topics. Questions for the first class session included, what are your views of teaching and learning? what is the problem with how science is usually taught? what are new perspectives on teaching and learning? During the first few class sessions (these were 2 ½ hours one day a week), I shared my views of what it means to "teach science as inquiry". Instead of using a direct teaching method (i.e. listing the steps for how to develop the best lecture or the best PowerPoint presentation or delivering handouts on best practices) I asked my Ivy League College doctoral science students this question, can you light a bulb with one battery and one wire? I handed around the batteries, the bulbs, and the wires. I then showed them a flashlight, turned it on, and asked them to draw a model of what is inside a flashlight. They shared their models with the person sitting next to them (electrical engineers with chemical biologists). Building on these personal experiences I showed a well known video clip from the Private University study of M.I.T. graduates, who were asked to take on the same task, yet stumbled in their attempts to give scientifically accurate explanations. I further modeled an inquiry-based approach by engaging students in a series of activities; all involving a scientific question, the use of observations, gathering data and evidence, developing explanations, and justifying their explanations. After each experience I stepped back, and deconstructed what had happened in the lesson. One of the modeled lessons was Tricky-Tracks or Fossilized Tracks described in the NRC book on Teaching Evolution and Nature of Science (1998), in which students develop a story of how two sets of tracks were laid down and fossilized. What happened? What is the evidence? What are your observations? What are your inferences? Did your story change after hearing others give their story? At each step I engaged my doctoral students in a whole class discussion of this lesson, originally designed in the 1960s for elementary students. Another model lesson on inquiry was the Cube lesson described in the NRC (1998) book. Using this example we discussed aspects of Nature of Science (NOS) that one could teach using this lesson, including that science is empirical, subjective, a product of human imagination and creativeness, and the distinction between observations and inferences (Lederman, 1992).

Near the end of the session I shared what I mean by ”teaching science as inquiry” – that of grappling with data and developing explanations of an event or phenomenon; of answering questions based on evidence and connecting developing understandings to the scientific understandings (see NRC, 2000). At the center of an inquiry-based approach is the student herself, making sense of something; of figuring out what is an explanation based on evidence, the process of grappling with data. I go on…isn't this exactly like how a scientist works? Like what you do? So, why don't we teach our students in similar ways to how scientists work and think?

I asked doctoral science students to read journal articles of science educational research (e.g. Furtak, 2006; Hodson, 1986; Schwartz, Lederman, & Crawford, 2004) and we debated the findings and significance of these readings in small groups. One central assignment was that of developing a teaching philosophy statement, which could later be used in an application for a teaching position in higher education. See Appendix B. The entire course syllabus, including the list of readings and description of assignments and class discussions, is available by email request of the author.

Findings

From analyzing the Pre-course Questionnaire, it was evident that although prospective college teachers expressed clear interest in teaching, most had had no formal experiences in learning about pedagogy. The responses of the following three students are representative. For example, Mary (pseudonym) was a 4th year Ph.D. student in Evolutionary Biology. In response to the pre-course questionnaire question, #6, List your previous education coursework, if any. (If none, please skip to #7), Mary responded, *I have not had the opportunity to take any education courses before now*. Another student, Kelly, was a 1st year graduate student in Food Science/Food Chemistry. She wrote, *the only thing I have done is I was an undergraduate TA and writing tutor for a few years.* A third student, Miriam, was a doctoral student in Chemical Engineering. Her research area was organic electronics and computation. Like many of the students at this research-intensive university she had no prior formal educational experiences, other than serving as a TA: She explained she had been a TA: *Chemical Eng. Undergraduate lab and involved in Outreach with CCMR: helped develop teaching activities on electromagnets.*

In response to the question, what are your primary goals for this course?, a few students mentioned inquiry, and based their pre-philosophies on models seen in previous courses they had taken. Mary, stated,

> *My main goals for this course are improving my teaching skills. I intend to be a professor, and in Ecology and Evolutionary Biology at (this university) the focus is very much on research to the exclusion of teaching. Teaching is viewed as "something you just go and do", but I want to be more prepared than that. A particular undergraduate course that employed inquiry based teaching methods was instrumental in my eventual career path; I would like to develop skills in this area so I can provide my students with similar enrichment. I am particularly interested in learning how to integrate inquiry-based instruction in the large, structured lecture-based classes I will be teaching.*

Kelly stated,

> *My main goals for this course are: ways to get students excited about the sciences. Too many people that I have met are afraid/intimidated by Chemistry (my first love ☺) and the other Sciences. I'd love to find a way of introducing material to students that will cause them to open their minds instead of just saying, "I don't get it".*

Miriam, a doctoral student in Chemical Engineering stated simply,

> *My main goals for this course are: find the best way to teach a lot of science in a short amount of time.*

In Miriam's case, her desire to be efficient and cover a lot of material is based on the reality of traditional expectations of college science teaching.

Related to the first research question, *what are prospective college instructors' emerging philosophies of teaching, and how do they change, if at all*, there was evidence that during the course my students had intuitive ideas about teaching science, and later evolved more robust philosophies of teaching during the course. Prior to taking the course all students expressed an interest in teaching. Indeed, that was the reason they signed up for the course. Their initial beliefs about teaching and learning were varied and mostly stated in intuitive/everyday language, grounded in their unique personal learning experiences. Many confessed they had never been asked to write a philosophy of teaching statement. In response to question #7, state what you would consider the central aspect of your current philosophy of teaching, most were cautious about putting forth their ideas. Early in the course Rachel (Ornithology) stated, "I'm not sure that I could currently articulate a philosophy of teaching." Kelly (Food Science) wrote, "To be honest, this is something I hope to develop throughout this class and I do not have a concise philosophy of teaching".

For those students who identified a central aspect of their philosophy they mainly focused on student motivation and interest, and the enthusiasm of the instructor. These students had some ideas, gained from their own interest in their discipline. Roland, a doctoral student in computer science and artificial intelligence wrote, "My objective when teaching any subject (be it first-order logic, training artificial neural networks or basic photographic technique) is to transmit my enthusiasm and love for the subject to my students. I want my students to experience the same sense of wonderment I have felt so many times when studying these topics." Juniper a 2nd year doctoral student in plant breeding and genetics wrote, "In order to really learn anything, a student must first have interest in the subject, so therefore the key to learning is first stimulating interest. Jeremy, wrote, "The central aspect to my current philosophy of teaching is that any student can be great in any field as long as they have the interest and willpower to push forward. It is a teacher's responsibility to cultivate that interest." Another example of this emphasis on student motivation and interest is Janine's response to Pre-Question #7:

> I think motivating my students is crucial. Helping them see that they are capable of achieving success. As a woman, I also want to help girls become comfortable with being 'smart', and good at science. It took me too long to realize that being a dork is WAY more fun than pretending to be something else. I hope that by

> being a cool, dorky teacher, my students won't feel intimidated. I also realize that being someone else is the name of the game in adolescence, so I hope I can at least lessen that burden… I guess my central aspect is being a fun, dorky teacher that students can relate to, as well as aspire to be.

Students' early philosophy statements were crafted from their personal learning experiences in both formal and informal education. Although their statements were true representations of their ideas of teaching, their ideas were not grounded in research, learning theory, aspects of teaching science as inquiry, or nature of science, as described in contemporary reform-based documents. As the course progressed these prospective college teachers revised their initial ideas, and in their "final" philosophy statements they included specific aspects of inquiry and nature of science and constructs such as constructivism. These emerging philosophy statements were all unique; students wove their initial intuitive ideas into a fabric of theoretical ideas gained from the course readings and class discussions. An example from a final philosophy comes from that of Kelly's:

> …My underlying goal as a teacher is to instill this similar ability upon my students and expose them to the world of science. I will implement components of constructivism, where my students will learn from their experiences, and the role of inquiry by connecting concepts to their everyday lives and encouraging them to explore new topics. I hope that they develop a true understanding of various chemical principles and learn how to critically think, so they can apply their knowledge to solve future problems that they may encounter. Ultimately, I want all of my students, despite their background, to learn how to think like a scientist by questioning aspects of their everyday lives and drawing conclusions based on evidence that they gather.

In their final philosophy statements *all* students specified several aspects of inquiry and nature of science, as illustrated by Kelly's excerpt. Kelly included two of the essential features of inquiry, that of questioning aspects of everyday life, and the use of evidence. A doctoral student in computer engineering, Lance struggled in early class sessions, and stayed after class to clarify some unsettling points in the readings. He and his office mate had debated the value of using these inquiry-based approaches versus more didactic and lecture-based approaches. In his final philosophy statement he wrote eloquently, "the key message to communicate here is that science (and math in particular) is not straightforward. That there are often many paths to the same goal." Due to a demanding research schedule one student submitted her philosophy only at the end of the semester, and wrote, "This is really late, but I still found it valuable to do. I found a reference to "transmission of information" in my old philosophy from grad school, so I rewrote almost the entire thing from scratch." The following is an excerpt from Dean, a doctoral student in chemical biology.

> Science is driven by the individual scientist's passion for learning and curiosity about the world and is built on the construction of knowledge through interactions within the scientific community. I acknowledge that providing students with authentic experiences in doing science is essential and as such, I will employ teaching

> strategies that involve inquiry and collaboration. I will teach laboratory courses which involve authentic questions and real-world problems that will engage students and develop their analytical and critical thinking skills as they design experiments, gather and process data, infer conclusions, justify claims and present their results to their peers

Audrey's pre-, early and later philosophy statements illustrate qualitative differences showing enhancement of views of teaching science as inquiry typical of the other students in this class. (See Table 1.)

Table 1.Qualitative Comparison of One Student's Pre-, Early and Later Philosophy Statements

Name	PRE-Questionnaire What is the central aspect of your current philosophy of teaching?	Early Philosophy Statements Excerpts	Later Philosophy Statement Excerpts
Audrey	Learning can and should be **fun.** Some of the best teachers I have had were the ones who were not afraid to put **themselves out there**, and be a little foolish in order to **inspire** their students, or make something **interesting** that might otherwise * Boldface added by author indicating emphasis on motivating students	(1 ½ pages total) I love horticulture. There is very little more satisfying to me than planting a tiny seed in the spring, and watching that seed sprout, grow, and mature into a giant watermelon, or mighty oak over the months and years. Essentially, though, the core of my teaching philosophy centers around the belief that inspiration is the food of the spirit.	(3 ½ pages total) I love horticulture. There is very little more satisfying to me than planting a tiny seed in the spring, and watching that seed sprout, grow, and mature into a giant watermelon, or mighty oak over the months and years. Science is much more than a set of facts. It is **a way of thinking about the world**…. .* The way many programs are currently structured, at the earliest stages, when their understanding and interest in a subject are yet nascent and fragile, students are only introduced to the driest, most deeply reduced factual information available on the subject. Further, they are introduced to these facts in a monotonous and uninspiring way, typically by being lectured with some transparencies or Power point visual aids. The logic behind this method seems to be that students are incapable of truly **thinking** about a subject without first having a solid grounding of facts at their disposal. I would like to challenge the nature of this idea, and suggest that students already have all of the tools necessary to **engage in a deeper understanding of the nature of science** when they first walk into the classroom at the beginning of the semester, if only they can be taught to use them. . I, as a teacher, **plan to introduce new concepts to the students first through carefully designed "problems" –** real world examples of phenomena that **scientists have had to work to understand**. Through **guided classroom inquiry discussions, students can probe, and begin to understand,** that at the very foundation of science there are people, just like them, asking the important and then working to **answer those questions.** * Boldface added by author indicating aspects of inquiry-based teaching

Results of analyzing Pre-, early and later philosophy statements for inclusion of aspects of inquiry and nature of science are shown in Table 2. A few of the students submitted their espoused philosophy statements only once, as indicated in the table. See Figure 1 for a graphical representation of students' growth.

Table 2- Quantitative Changes in Aspects of Inquiry/NOS included in Pre-, Early, and Later Philosophy Statements

Name	**Discipline**	**PRE-Questionnaire Central aspect (Number of inquiry and NOS concepts)**	**Early Philosophy Statement (Number of inquiry and NOS concepts)**	**Final Philosophy Statement (Number of inquiry and NOS concepts)**
Audrey	Horticulture/Apple Breeding	0	1	6
Kelly	Food Science	0	2	8
Juniper	Plant Breeding and Genetics	0	-	11
Janine	Genetics, genomics, reproductive biology (Post-doc)	0	4	- left for research in field before end of semester
Rachel	Ornithology	0	-	8
Lynn	Biology	0	4	7
Eileen	Plant Biology	0	4	4
Lance	Mathematics and Computer Science	0	2	7
Kole	Electrical Engineering	0	2	3
Dean	Chemistry/Chemical Biology (profiling proteins known as proteomics) 4th year	0	-	9
Mean		0	1.9	6.3

Students included on average more than six aspects of inquiry and NOS in their final philosophies, versus none in their pre-philosophies.

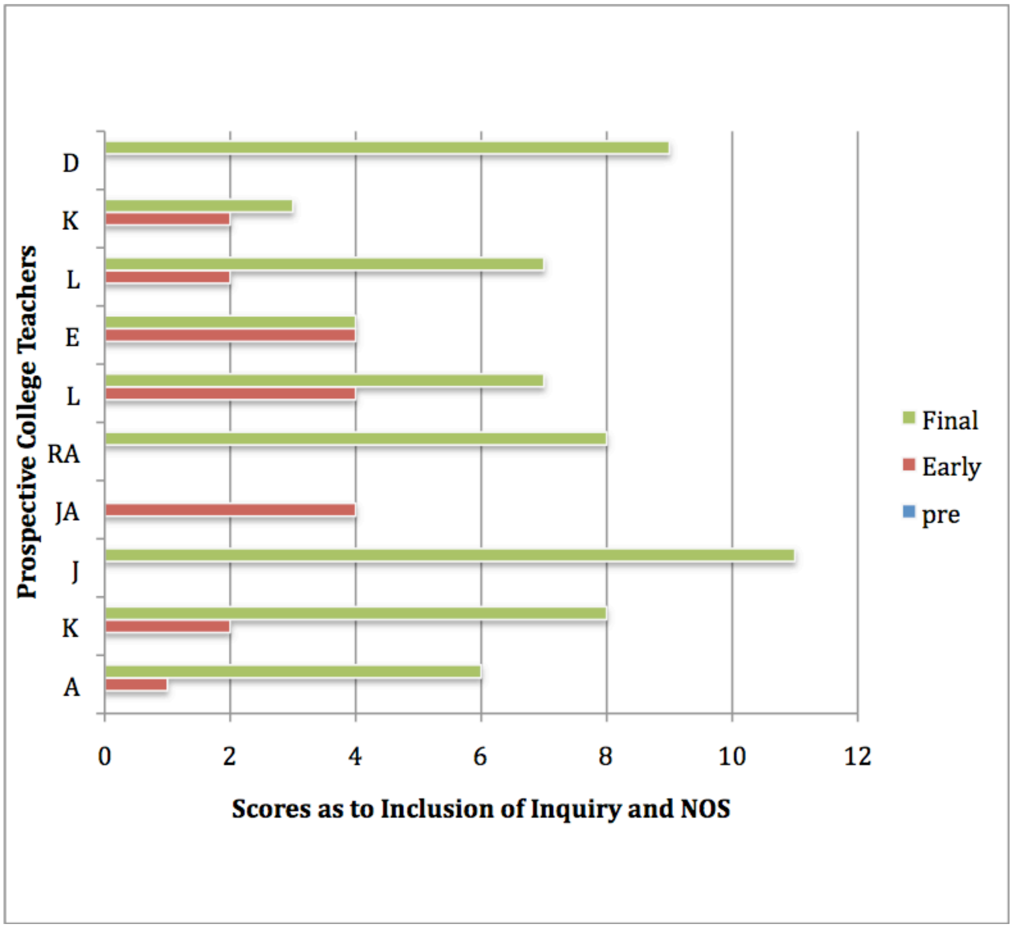

Figure 1. Increase in aspects of inquiry and NOS articulated in prospective college instructors' philosophy statements from beginning to end of course. (Score of 0 for each student's Pre)

To answer the second research question, 2) *what is the evidence that prospective college instructors develop an understanding of teaching science as inquiry,* a comparison was made of students' Pre-views of inquiry and features of inquiry in their developed lesson plans. Lesson plans were viewed for the essential features of inquiry (NRC, 2000). For the purpose of this paper, an in-depth systematic analysis was not performed; but rather a qualitative comparison made in order to get a sense of the kinds of lessons these students developed, and if, indeed, there were features of inquiry in students' goals and lesson components. Evidence of understanding what it means to teach science as inquiry included goals and objectives of the lesson, the sequencing of the lesson components, and opportunity for students to grapple with data, use evidence to develop explanations, and draw conclusions. In contrast, a lesson characterized as traditional and teacher-directed might depict students passively receiving subject matter information (primarily through note taking, lecture, or reading), with limited time for discussion and debate.

On the Pre-questionnaire, most students attempted to give a response to question 8, what is inquiry-based science teaching? A typical response mentioned something about "answering questions", but the statements were vague. For example, Rachel (3rd year Ornithology) wrote, "I think it's when you have the student try to figure out the lesson for themselves through experimentation, but I don’t really know.” Andrea, a doctoral student in Plant Breeding offered a definition, “I would think this is a teaching method where you either ask a question or have the students ask a question, and then go about trying to figure out the answer. But that is just a guess…”

For their designed lessons and peer teaching students addressed a range of sophisticated concepts including, Einstein's Special Theory of Relativity, Animal Behavior, Introductory Algorithms, DNA, Fossils, Nonlinear Dynamics, Computer Engineering, and Proteomics. Their instructional designs varied from a few pages to chapter length descriptions of the sequence and substance of an entire unit of instruction. Excerpts from representative instructional plans appear in Table 3. It is evident these prospective college instructors included at least some aspects of the essential features of inquiry in their plans, along with student-centered strategies, in particular focusing on scientifically oriented questions, use of critical thinking, and promoting collaboration.

A surprising outcome of the ITS course was the fact that, on their own initiative, a few students strived to translate their research into actual teaching episodes for precollege teachers to use in their classrooms, for the public. After the course had ended, some students wrote and published articles in peer reviewed teaching journals about how to transform their scientific research to make it more understandable to pre-college students. Others included an additional chapter in their final dissertation, focused on pedagogy.

Table 3 Prospective College Teachers’ Pre-Views of Inquiry and Evidence of Inquiry-based Features in Lesson Plans

Name	**Degree/Level**	**PRE- What is inquiry-based science teaching? Beginning of course**	**LessonTopic/ Concepts**	**Statements in Lesson Plan related to Innovative Teaching Components End of Course**
Dean	Chemistry/ Chemical Biology (profiling proteins known as proteomics) 4th year	Do not know.	“Proteomics” designed for an undergraduate biochemistry course	The students will be able to design a gel-based comparative proteomics experiment, which involves proteome isolation, analysis and comparison… Discuss with their group mates their ideas …The students will be able to complete a pre-lab report explaining how they will perform the comparative proteomics experiment.
Kole	Electrical Engineering	A strategy aiming to arm students with their own internal motivation to discover and ask on their own, which is the best way to have students choose science as their own discipline.	Einstein's Special Theory of Relativity	Inquiry and student centered strategies’; Animations, thought experiments, historical experiments will provide a hook for students; Heavy emphasis on discussion - questions posed will be thought provoking for all, Students will question each other questioning and reflection. A class environment where everyone can bounce ideas off each other would enhance understanding greatly.
Lynn	Biology Ph. D. University instructor of the Intro Bio labs	It is setting up your instruction so that students directly create their own knowledge actively instead of passively absorbing it from an instructor? (not sure)	Antibiotic Resistance For freshmen, biological science majors and premedical students	Goals For students to understand/analyze how antibiotic resistance emerges and its effects. For students to learn how to interpret graphs of their own and other example data to develop scientific explanations/hypotheses.

Name	Degree/Level	PRE- What is inquiry-based science teaching? Beginning of course	LessonTopic/ Concepts	Statements in Lesson Plan related to Innovative Teaching Components End of Course
Kelly	Food Science, Chemistry 1st year grad	Science teaching based around questions. In other words, a student asks an initial question and the teacher tailors the lesson around that question. This kind of teaching would encourage drawing hypotheses and testing them.	The Science of Food	Students are introduced to and explore the types of new products that exist; Students are introduced to the 8 considerations in product formulation • Students come up with their own idea for a new product, using their own creativity and knowledge about the science of food • Students work in groups to refine ideas and pick the best idea for a new project within their group, modeling the real product development process To begin the lesson, I will try to engage the students by starting off with a discussion about the new product Banana Nut Cheerios, and will bring in samples to help encourage their involvement.
Jason	Electrical Engineering/ Computer Science	(No response.) I'm concerned that I might not have the appropriate pre-requisites,	Introductory Algorithms	**Driving Question** We all sort things in our daily lives: the mail, books, clothes in our closet. We all have our own, different methods of sorting things that we really like, because they work for us, they feel right. The same is true for computers: say you're trying to organize your MP3 collection alphabetically by artist. There are lots of different ways you can sort a set of data alphabetically, but which one do you choose? • Students should understand the tradeoffs between computational time and memory usage in sorting algorithms (and begin to see applications to other algorithms). • Students should also understand how these characteristics change as implementation details change.

Discussion and Conclusions

The prospective college instructors in this study had a personal interest in enhancing their abilities to teach science. These students attended the ITS class, in spite of other pressing obligations to do their research and publish their scientific findings. For the most part, they were open to change. They thought about, and in many cases, appeared to embrace new ideas about aspects of nature of science, something most of them had not thought about before the course. They strived to understand what it means to teach science as inquiry, and to develop plans they might actually use in their future teaching. Students began the course with naïve views of what it means to teach science as inquiry and developed more robust philosophies of teaching science. In final espoused statements all students showed movement towards student-centered and inquiry-based approaches.

Whether or not these prospective college instructors will go on to actualize these ideas in their future courses, they were at least open to exploring the language and concepts. In each case, these prospective college teachers did not simply list the essential features of inquiry and the tenets of nature of science, but tried to weave them into their original pre- and early philosophy statements, and strived to connect their developing ideas with their individual areas of science.

In final course evaluations they rated the class discussions of the readings, as the most important component of the course. Some of them saw themselves in the readings, remembering their early college years and feeling that science is often inaccessible, due to the way science is taught in many universities (Tobias, 1990).

The findings of this study add to the limited research on inquiry-based teaching at the college level. It is true that these students were poised for change, and changes seen in these students would likely not be seen in a more reluctant sample. Changes in prospective college teachers' personal philosophies of learning and teaching science paralleled those of prospective secondary science teachers in a previous study (Crawford & Lunetta, 2002). The importance of college teachers developing a wholly owned philosophy of learning and teaching science aligns with findings of Gess-Newsome et al. (2003), related to the influence of personal practical theories. Gess-Newsome et al. (2003) state that grants may aid in taking away some of the structural barriers to change, but grants alone may not be sufficient for change. They suggest that if college instructors are generally dissatisfied with a particular pedagogy, then this can create a context for fundamental change. Their findings point to the idea that "personal practical theories" are the most powerful influence on instructional practice. These personal practical theories, or what I refer to as personal philosophies of learning and teaching science, need time and support for developing ideas and time and prompting for revision, as most prospective college teachers have had few non-traditional educational experiences from which to draw upon, nor do they have the language or access to the science educational research to develop their formalized ideas of teaching. The main avenue for change in the way science is taught at the college level may be in developing robust personal philosophies that guide a college instructor in enacting student-centered, inquiry-based approaches when designing and teaching a course.

Implications for College Science Teaching

Shipman (2004) optimistically suggests that, regarding college science teaching, *the times they are a changing.* Yet, as the world economy struggles, the times may not be a changing after all, in most undergraduate introductory college science lecture halls. I serve on a university *ad hoc* committee to completely restructure the introductory biology courses at my university. What is unclear after two years of planning is the actual amount of support in terms of TAs these biology professors will receive, as they work through the process of including more active learning and inquiry-based opportunities in their laboratory-based courses.

As teachers we rarely see immediate results of our efforts on our students, and it may be years later that we ever learn of any influence of our teachings. While I was writing this paper, I received an unsolicited email from one of my former IST students. I include the contents of his email below:

> August 2009
> I am currently printing out the Nature of Science activity we did in our IST course with the numbers and names on the cube for my Non majors Chem course I am teaching this fall. I thought of you and thought you would be pleased to know the effect of your efforts on now my full time job of teaching undergraduates science. I am excited and nervous all at the same time, as I attempt to do this vocation of teaching. I think I am afraid with three new courses this fall and 8 lectures to prep for a week, that I will lapse into a teaching style which just gets it done, rather than try to think and reflect on how best to teach the material. I remind myself that it will likely take me years to become a

skilled educator. Thanks for helping me in that process. Hope all is well and you are excited about the coming semester.
All the best,
Sam Assistant Professor of Biochemistry University X Wisconsin USA
~~~~~~

The tagline on Sam's email is a quote from Albert Einstein: "The important thing is not to stop questioning. One cannot help but be in awe when he contemplates the mysteries of eternity, of life, of the marvelous structure of reality. It is enough if one tries merely to comprehend a little of this mystery every day. Never lose a holy curiosity." --Albert Einstein

Implications for Further Research

The findings of this research suggest that, given opportunity, prospective college instructors can learn about and articulate reformed-based teaching approaches, and begin to think about using less teacher-directed, lecture-based modes towards more student-centered, inquiry-based approaches. What we do not know is the extent to which college professors, who express views of teaching science as inquiry, can sustain their intentions to, or are able to, design inquiry-based learning environments in their college classrooms. To what extent can these novice college instructors develop practical knowledge that will serve them and sustain them in their unique contexts? (See Driel, v., Beijaard, Verloop , 2001.) Needed are more studies, such as one conducted by Gess-Newsome, et al. (2003) exploring the enactment of inquiry-based teaching approaches in actual college classrooms, across the range of large, highly competitive, research oriented universities and small teaching-focused college settings. Additionally, we need to understand the constraints to this kind of teaching, which may have no immediate payoff for an untenured science faculty member at a research university. Finally, we need to understand more about how to support new college professors, such as Sam, as he navigates the unchartered territory of innovative teaching.
~~~~~~

References

Anderson R.D. (2002). Reforming Science Teaching: What Research Says About Inquiry, *Journal of Science Teacher Education, 13, (1),* 1-12.

Brown, A. L. (1994). The advancement of learning. *Educational Researcher, 23*, 4-12

Brown, P., Abell, S., Demir, A., & Schmidt, F. (2006). College science teachers' views of classroom inquiry, *Science Education, 90, 5*, 784-802.

Cobb, P. (1994). Where is the mind? Constructivist and sociocultural perspectives of mathematical development. Educational Researcher, 23, 13-21.

Creswell, J. W. (1998). Qualitative inquiry and research design. Thousand Oaks, CA: Sage Publishers.

Crawford, B. A., Krajcik, J. S., Marx, R. W. (1999). Elements of a community of learners in a middle school science classroom. *Science Education* 83(6), 701-723.

Crawford, B. A. & Lunetta,V. (Fall, 2002). Promoting the development of a personal philosophy of teaching in prospective secondary science teachers. *Pennsylvania Teacher Educator, 1,* 68-74.

Driel, J. H. v., Beijaard, D. , Verloop, N. (2001). Professional development and reform in science education: The role of teachers' practical knowledge. *Journal of Research in Science Education* 38(2), 137-158.

Driver, R., Asoko, H., Leach, J., Mortimer, E., & Scott, P. (1994). Constructing scientific knowledge in the classroom. *Educational Researcher, 23*, 4.

Furtak, R. (2006). The problem with answers: An exploration of guided scientific inquiry teaching. *Science Education, 90 (3*), 453-467.

Gess-Newsome, J., Sutherland, S., Johnston, A., Woodbury, S. (2003). Educational reform, personal practical theories, and dissatisfaction: The anatomy of change in college science teaching, *American Educational Research Journal, Vol. 40, No. 3*, 731-767.

Hodson, D. (1998). Is this really what scientists do? Seeking a more authentic science in and beyond the school laboratory. In J. Wellington (Ed.). Practical work in school science: Which way now? (pp 93-108). London: Routledge.

Lederman, N. G. (1992). Students and teachers conceptions about the nature of science: A review of the research. *Journal of Research in Science Teaching, 29,* 331-359.

Miles, M. B. & Huberman, A. M. (1994). Qualitative data analysis: An expanded sourcebook. Thousand Oaks, CA: Sage Publications.

National Science Board. (1996). Science and engineering indicators. Washington, DC: US Government Printing Office.

National Research Council. (1996). National science education standards. Washington, DC: National Academy Press.

National Research Council. (2000). Inquiry and the National Science Education Standards: A guide for teaching and learning. Washington, DC: National Academy Press.

Schwab, J. J. (1962). The teaching of science as enquiry. In J. J. Schwab and P. Brandwein (Eds.), The teaching of science (pp. 1-103). Cambridge, MA: Harvard University.

Schwartz, R. & Crawford, B. A. (2004). Authentic scientific inquiry as a context for teaching nature of science: Identifying critical elements for success. In Scientific inquiry and nature of science: Implications for teaching, learning, and teacher education (Eds. Flick, L., & Lederman, N.). The Netherlands: Kluwer Publishing Co.

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*, 610-645.

Shipman, H. L. (2002). The prevalence of active learning strategies at the University of Delaware, Fall 2001, Available on the World Wide Web.

Shipman, H. L. (2004). Inquiry learning in college classrooms: For the times they are a changing. In Scientific inquiry and nature of science: Implications for teaching, learning, and teacher education (Eds. Flick, L., & Lederman, N.). The Netherlands: Kluwer Publishing Co.

Solomon, J. (1989). The social construction of school science. In R. Millar, Doing science: Images of science in Science Education. London, New York, Philadelphia: The Falmer Press**:** 160-179 .

Solomon, J. (1993). The social construction of children's scientific knowledge. In P. J. Black, Lucas, A. M., Children's informal ideas in science. London: Routledge**:** 85-101.

Tobias, S. (1990). They're not dumb, they're different; Stalking the second tier. Tucson, AZ: Research Corporatio

Vygotsky, L. S. (1978). Mind in society: the development of higher mental processes. In V. M. Cole, John-Steiner, & E. Souberman, (Ed.). Cambridge, MA: Harvard University Press.

Wood, T., Cobb, P., & Yackel, E. (1992). Change in learning mathematics: Change in teaching mathematics. In H. Marshall (Ed.), Redefining student learning. New Jersey: Ablex.

APPENDIX A

Pre-Course Questionnaire

Innovative Teaching in the Sciences Spring 2009

Please complete this questionnaire on your background and goals for this course, and your views on science and teaching, and submit it in the Digital Dropbox on the Course Website as soon as possible—before our next class.

1. Name (last, first)
2. Check one or more that apply:
 a) I have officially enrolled in the course ___
 b) I intend to stay enrolled in the course this spring 2008 (2009?)___
 c) I have not yet registered in the course, but I would like to _____
 d) I have registered as an Audit for the course ___
 e) I have registered, but I now have decided to wait until next Spring to take it __
3. Major Area of Science or other area:
4. Possible topic or concept for the instructional plans you will develop and circle the level of instruction (elementary; secondary; undergrad; graduate; extension, other):
5. Year or Level of your Graduate work:
6. List your previous education coursework, if any. (If none, please skip to #7)
   a) Briefly describe your teaching or outreach experiences, if any.
   b) Briefly describe your research area (scientific or educational)
7. What are your primary goals for this course?

Please complete the following questions on your Views of Science and of Teaching and Learning Science. If you do not know an answer to a question, just write—do not know. Do your best. Write as complete answers as possible. But, do not worry if you cannot answer a question.

8. What is inquiry-based science teaching?
9. What is constructivism?
10. What, in your opinion, is science? What makes science (or a scientific discipline such as physics, biology, etc.) different from other disciplines of inquiry (e.g., religion, philosophy)?
11. After scientists have developed a scientific theory (e.g., atomic theory, evolution theory), does the theory ever change? Explain and defend your answer with examples.
12. Distinguish between an observation and an inference.
13. The "scientific method" is often described as involving the steps of making a hypothesis, identifying variables (dependent and independent), designing an experiment, collecting data, and reporting results. Does good science need to follow the scientific method? Explain your answer.
14. Does the development of scientific knowledge require experiments? If yes; explain why. Give an example to defend your position. If no; explain why. Give an example to defend your position.
15. After scientists have developed a scientific theory (Atomic theory, evolution theory), does the theory ever change? Please explain/ defend your answer and give an example.
16. Is there a difference between a scientific theory and a scientific law? Illustrate your answer with an example.
17. State what you would consider the central aspect of your current philosophy of teaching.

Thanks very much for your help. I'm looking forward to your participation in *Innovative Teaching in the Sciences.*

APPENDIX B

IST Writing Your Philosophy of Teaching

A philosophy of teaching should address how you believe students learn your discipline and how best to teach your discipline. You should include your beliefs about the nature of your discipline, for example, nature of science. These statements will be an important part of your Teaching Portfolio.

→You may want to include citations of any readings in support of your statements as well as your personal experiences.

Here are some prompts for writing your Philosophy of Teaching

Your Philosophy of Science Teaching

Focus on describing your current philosophy of science teaching. How would you describe your role as a teacher? Describe predominant teaching strategies you use and hope to use in the future. What role will inquiry and technology tools play in your teaching? Explore some of the reasons you are interested in becoming a teacher. Describe the type of science instructor you would like to become. Describe specific teaching strategies that you feel comfortable trying out. You might describe teaching strategies/approaches of your favorite and least favorite science teachers/professors and discuss how these individuals have influenced your own emerging philosophy of science teaching. Try completing the following prompt: "An effective science instructor is one who . . How will you interact with them? How will you work toward meeting the goal of "science for all?"

As part of your philosophy of teaching statement, you could also include statements related to nature of science and nature of science learning (or learning your discipline). Integrate these statements into your teaching philosophy.

I. Nature of Science

Many of us identify ourselves as students of specific science disciplines, such as biology, earth science, physics or chemistry. What characteristics do all these disciplines have in common? How is new knowledge generated in science? What makes something "Science" as opposed to "Literature"? Many of your future students will not become scientists, what would you like them to understand about nature of science as a result of having been a student in your classroom? Which aspects of the nature of science do you feel are the most important for your students to understand?

II. Nature of Science Learning

How do you best learn science (or your discipline)? Describe science teaching and learning strategies that have been successful for you as a learner. What is required to be a successful student in high school and college science courses? Is there a difference between earning good grades in science and understanding scientific concepts? Try completing the following prompt: "I think students learn science best when . . . (image of learner and curriculum – *how* one learns and *what* one learns.)" Make a series of claims about how you think students best learn science Draw on your experiences observing students and teaching them, as well as readings and class discussions. Be sure to include a discussion of your current thinking about constructivism and the role of inquiry in learning science.

APPENDIX C

Philosophy Statements Coding and Scoring for Inquiry/NOS 15 total possible points

Features of Inquiry (**Essential Features of Inquiry (IQ)** (NRC 2000)
ONE • Students should be taught that science is one way of knowing about the world, based on the use of evidence to develop explanations about how things happen in the world,
MET • Scientists use many methods. There is no single scientific method
INT • Inquiry is a set of interrelated processes by which scientists pose questions about the natural world.
QUE • Scientifically oriented questions
PTE- • Give priority to evidence in responding to questions
EFE- • Formulate explanations from evidence
SCI • Connect explanations to scientific knowledge
COM • Communicate and justify explanations

Teaching about Nature of Science (NOS) (Lederman)
EMP • Science is empirically based using observations from the natural world
TEN • Science is tentative (subject to change)
OBS • Observations versus Inferences
STL • Scientific Theories and Laws (related but not hierarchical)
CRE • Science is a product of human creativity and imagination
CUL • Science is culturally and socially embedded
SUB • Science is subjective