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Facilitating Students' Argumentation Skills in a Physical Science Course for Pre-service Teachers.

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Argumentation is the cornerstone of the scientific endeavor (Duschl & Osborne, 2002), and the focus of efforts to improve science education, both post-secondary (SENCER 2012), and K-12 (Next Generation Science Standards 2012; Common Core Standards 2012). In our upper level integrated physical science course (PHSC) for pre-service and in-service middle level teachers, we attempt first to tease out the understanding of argumentation with which students come to our class, and secondly to find ways to introduce college students to the proposition that scientific facts are arguments that have been settled through the evaluation of evidence by scientific communities. In PHSC we attempt to introduce students to the concept and experience of “arguing to learn” (Andriessen, 2006); we have found promising a modification of Rosebery & Warren’s “Science Talks” (2011) to introduce pre-service teacher candidates to argument within the science classroom. In the participation structure (Erickson, 1982) we have developed, students puzzle out explanations for phenomena by talking with each other rather than being told facts by “the professors.” We ask students to conduct “explanatory inquiry” (Andriessen, 2006, p. 9) as they engage in public Science Talks. Focusing on the production of inscriptions (Lenoir 1998), more commonly called representations, allows students to build a consensus explanation for the scientific model we are considering.

Over several iterations of the course we have become convinced that Science Talks are the most productive feature of our the curriculum, providing for deep learning of both science content through the processes of science. If we expect middle level teacher candidates to prepare young adolescents for a world in which knowledge of science is essential for citizenship and success (Next Generation Science Standards, 2012), then clearly postsecondary science educators must provide pre- and in-service teachers with an understanding of the nature of science as well as content knowledge. Recognizing that responsibility, we share this account.

Theoretical Framework

Our work with students in PHSC and our design of the course is founded on three strands of scholarship: constructivist learning theory, studies of the nature of science (NOS), and social practice theories of learning. We understand all three of these intellectual commitments to be essential insights for teaching science for understanding at any level.

Constructivism

Constructivism ascribes learning as a process or an act undertaken by learners, running counter to pervasive essentialist notions of science as a fixed body of knowledge (Hacking, 1999). Undergraduate teacher candidates who are unfamiliar with learning theory generally, and constructivism particularly, have difficulty understanding the implications of learning as the building of knowledge within the individual and the community; such an experience is unsettling and often engenders disequilibrium, even hostility. For example, one male student, who was not always adept at gaining the floor during the give and take of conversation, complained on a course evaluation, “She [the professor] knew I knew the answer and still did not call on me.” We infer that this student, and likely many others, understood the purpose of answering professors’ questions to be a demonstration of competence in a competitive environment.

In order to defuse some of the students’ resistance to Science Talks, we have found it beneficial to introduce them to principles of constructivism as they apply to science teaching. Although this is not technically within the purview of a content course, since the students are all education majors just beginning their first course in learning theories, they are generally open to such ideas. For the last two years, one of the early activities of the course has been the reading and discussion of the essay, “The Virtues of Not Knowing” by Eleanor Duckworth (2006). Duckworth described a young child’s processes of coming to understand a complex volume problem through reasoning and experimentation. Interestingly, PHSC students—future teachers— consistently displayed a great deal of difficulty in following the development of the child's thinking. It appears to us that the notion of understanding learning as "thinking through" is outside the students' lived experience of education, which we find troubling. Still, Duckworth's proposition that *not knowing* puts children in a position to construct deep and meaningful knowledge resonated with most class members. It seemed to engender a positive emotional response and introduced the possibility that valuing what they "don't know" might be an acceptable jumping off point for discourse in PHSC. As the course unfolded, we repeatedly placed students in the position where they were asked to think through ideas.

Our use of Science Talks falls within the general category "pedagogies of engagement" focused on faculty-student and student-student interaction (Smith et al. 2005). In our work we extend the concept of cooperative learning beyond individuals collaborating in small groups, to the condition in which the entire class (admittedly a small class of less than 30), builds ideas together and sees the collective as essential to the process of coming to know. Active learning strategies, in the constructivist sense, are vehicles instructors employ to foster students' engagement with science in undergraduate education; they offer a pathway for conceptual change with regard to the relationship between experimental evidence and scientific theories (Singer, Nielsen, & Schweingruber, 2012).

Model-building is one fruitful strategy (Clement, 2008) we use to help stimulate learning about the nature of science. Through an oral format the class as a whole goes through process wherein students make observations, share conceptual models they have generated to help explain observations, work in pairs to evaluate the proposed model, and return to the large group to revise the model or propose a "better fitting" model. Although many researchers have turned to current technologies as interactive means for enhancing learners' skill we find these discussions do a good job of mediating conceptual change.

Social Practice Theories of Learning

While constructivists have in recent years taken notice of the fact that students in classrooms engage in social interaction which can be harnessed for learning (Bransford et al., year), they focus on individual learners (Lave, 1996). Conceptual tools embodied in social practice theories (SPT) allow us to understand learning to be mediated by and through participation in social groups. Barbara Rogoff conceptualizes learning as "a *process of transformation of participation* itself, arguing that how people develop is a function of their transforming roles and understanding in the activities in which they participate" (1994, p. 209, italics in original). In the SPT model of learning, theorists such as Etienne Wenger (1998) understand knowledge and beliefs to be constructed as social practices. The core idea of SPT is that social interactions *mediate* learning. "[B]eing human is a relational matter, generated in social living, historically, in social formations whose participants engage with each other as a condition and precondition for their existence" (Jean Lave, 1996, p. 149). Learning is a collective and social phenomenon rather than a "one-way" process from teacher to student (transmission model), or a psychological process of individual discovery (discovery or individual constructivist model).

From the SPT perspective, identity mediates the ways in which people interact. In social life, interaction creates our ideas about what our actions mean, and our collective ideas about what our actions mean create bounded spaces, "figured worlds" which exist only in the collective minds of its inhabitants (Holland et al. 2001, p. 49). In a particular figured world certain actions are meaningful to others and some are not. Wenger (1998) calls common practices a "shared repertoire of practice" (pp 82-84), and identity "a lived experience of participation" (p. 151).

SPT theorists consider that participation in social life mediates all human activity: thinking, doing, and who we are in the world. Lev Vygotsky (1978) developed his theories of learning, which sadly are often reduced to the "zone of proximal development," by thinking through the implications of the fact that children learn to speak through social interactions and then language mediates further learning. Learning is accomplished through participation in social activities, which exist through historical social practices—language, representations and collaborative activity (Yrjo Engestrom, 2000). Semiotic tools structure and are structured by action and thought in recursive fashion.

We use social practice theories of learning (SPT) to provide insight into the persistence of our students' ideas that science is a body of known facts rather than a culturally-sanctioned process for understanding explanations of observed phenomena. From a cognitive perspective, an individual student's increased abilities to provide evidence for scientific claims depends on her incorporation of new information into previously existing schemas, with a resulting reorganization of knowledge to include new ideas. Our understanding of the cognitive/constructivist paradigm played a major role in our efforts to investigate students' ideas about science. However constructivist theories of learning did not adequately explain students' apparent incomprehension of the practices of "doing" rather than memorizing science. Understanding epistemological beliefs as socially mediated, and a part of who students think they are, allows us to explicitly challenge their ideas about what learning science means, and to create opportunities for them to live a new experience of participation in science.

Nature of Science

In addition to being a body of knowledge, science is a human cultural endeavor with specific social practices, as well documented in sociology of science studies (Ochs et al. 1996; LaTour 1987; Lenoir 1998). We use the definitions developed by Andreas Reckwitz, "[S]ocial practices are sets of routinized bodily performances… [and] are at the same time sets of mental activities" (2002, p. 250). The practice is a social performance, actions and talk, which is recognizable as purposeful to other members of the community. Practices which are not recognized as meaningful to others in a group are not taken up or understood (Wenger 1998; Gee 2004). SPT is a powerful explanatory tool for understanding situations such as our integrated physical science course, in which students' repertoire of social practices did not allow them to make sense of the idea of science as "not knowing," nor to understand learning as the reorganization and testing of ideas.

Scientific inscription is the term we use for non-textual representations of scientific concepts, such as diagrams, charts, graphs and illustrations. Scientists use inscriptions to mediate thinking about their ideas, and their refinement is part of the process of coming to understand the meaning of evidence (Lunsford et al., 2007).

We consider traditional, essentialist ideas about science to be a paradigm in the Kuhnian sense, that is, as a matrix of values, theories, and beliefs about the nature of reality (Stanford Encyclopedia of Philosophy, 2011) within and through which scientific knowledge is constructed. SPT and individualistic theories are competing paradigms, methodologically and semantically incommensurate, to rearrange Kuhn's words (1996). The methodology of studies of students' learning in both paradigms may include collection and analysis of instructors' and students' interview responses, answers to questionnaires, classroom observations, and quantitative measures such as pre- and post-tests of science content knowledge and assessments of learning gains. There is, however, a considerable gulf between units of analysis, research questions asked, and meaning assigned to data. Social practice theories do not look at individual actors' purposes, individual learning progressions, or the norms they have internalized, nor their explicit or implicit knowledge and beliefs; rather we seek to locate the boundaries created by students' shared repertoire of social practices and to use that knowledge to introduce to students the practices of science. In our paper we focus on what we have found out about our students' trajectory in learning to create scientific arguments, in which "the scientific method" is a process for determining the validity of claims rather than a series of procedures to validate a hypothesis (Kuhn 1996).

Methods

The Course and the College

The challenges associated with this course are considerable. It was designed in response to state requirements that middle grades teachers pass three upper level content courses in each of two teaching fields; in our program one of the two must be language arts. Moreover, the Middle Grades program at our college is committed to educating all teacher candidates broadly, including upper level science (and upper level mathematics and social studies), regardless of intended content concentration. Therefore the majority of students in the course have no particular commitment to learning science, and even science concentration students usually do not have prerequisites for upper level courses in chemistry, physics or biology.

Course activities. One goal for our course, which is self-imposed, is to provide science concentration candidates with the background in physical science which will appear on the state middle level science content examination they generally take the summer after junior year.

Physical science content on the conceptual state test includes scientific models of the atom, kinetic molecular theory (KMT), energy, electricity, Newton's laws, and earth science including plate tectonic theory and astronomy. We have found that the test heavily concentrates on KMT and Newton's laws; in the past two years we have covered atomic theory, KMT and energy transfer in considerable depth and skimmed Newtonian mechanics. Plate tectonics is a topic of the geography course students take concurrently with PHSC, and in 2012 we dropped it from the syllabus so we could spend more time on NOS.

For the past two years we have given the following assignments and activities:

- A science autobiography written in the first class. We affixed poster papers covering the years of our students' lifespan, generally the last 20 years, on about 50 feet of wall in the corridor outside the classroom. Students wrote highlights from their memories of science learning in the appropriate year. As a class we moved from year to year and invited comments on what students had written.
- The Checks Lab, an activity on the nature of science downloaded from the Evolution & the Nature of Science Institutes (ENSI) at the University of Indiana (ENSI 1999). This was used to facilitate a discussion of the ways in which scientists use data to support claims.
- Models of the atom prior knowledge prompt. We asked students to create on a poster a model of an atom. In 2011 this was done by individuals and in 2012 by pairs of students. We asked students to view each model and affix Post-It Notes stating what, in their opinion, was "good" about the model. What did the model accurately show about the structure of the atom?

- Journal prompts (on paper in 2011, electronic in 2012) taken from the Views on the Nature of Science Questionnaire VNOS (Abd-El-Khalick et al., 2001), asking students their ideas about the nature of science.
- A “Light Tour of Collegetown.” We provided diffraction grating glasses to each class member and walked the streets of the small downtown after dusk to make observations about the spectra that were revealed through the glasses.
- Inquiry-based laboratory investigations, including electrolysis of water (2011 only), determining the calories in food, flame tests of metal ions, emission spectra of gases, heating curve of ice, observation of light through colored filters.
- Inquiry-based computer simulations from PhET (University of Colorado, Boulder 2011). These mainly focused on theories of atomic structure and behavior of light.
- “Present to a Scientist.” Students were given articles (2011) or book chapters (2012) which contained accessible yet high-level factual information. Volunteers from the Chemistry and Physics Department faculty met with small groups of students assigned to articles to unpack the content. The students then presented to an audience consisting of the faculty and other interested observers from the Middle Grades program.
- “Science in the Media.” Pairs of students were assigned to locate Internet articles about science news, evaluate the validity of the evidence provided, and discuss the role of authority in science.
- Inquiry lesson plan for young adolescents. This was the culminating performance assessment for the course. Small groups were charged with creating an inquiry lesson plan suitable for middle level students. This has always been an unsatisfactory assignment because our students tend to avoid intellectual challenge in their lessons. We

have attempted to change the rubrics but the products have generally not improved. Students at this stage in the Middle Grades program have just been introduced to lesson planning, which may be part of the cause.

- A Moon Journal, in which each student observes or attempts to observe the moon for 30 consecutive days. We then as a class look at the compiled data and attempt to construct an model of the sun-earth-moon system based only on the data.
- Required readings: an informational text which includes content as well as the history and nature of science; a book on school science, such as Wynne Harlen's *Primary Science* (2001), Internet sites which provide content information and serve as textbooks; and the aforementioned essay by Eleanor Duckworth (2006).

Students. Cohorts of approximately 20 students are admitted to the Middle Grades program as juniors in the fall, and take all courses as a cohort during that semester. The selection process is competitive; not all who apply are admitted. Candidates are chosen on the basis of completion of required coursework, grade point average and interview. The classes are predominantly White women; 2011 saw an outlier class which included 6 men and 14 women. In all other years, however, there have been 1 or 2 men in classes ranging in size from 17 to 29.

There are usually a few graduate students in the class, although none in 2012. These are in-service teachers taking a concurrent graduate section as part of an MEd program. We have focused this paper only on the experience of the undergraduate students.

Generally about 25% of the class intend to become science teachers and have at least some first-year science preparation. A significant proportion (usually about half) agrees with some form of the statement, "I hate science;" a few transfer students have successfully avoided taking any postsecondary science until they were forced to enroll in integrated physical science.

One woman, who had transferred to education after two years of pre-nursing, told the authors, “I switched from nursing so I would never have to take another science class, and here I am.”

Over the years this course has been taught by various members of the chemistry department, with significant collaboration of education and science faculty. One or another of the authors of this paper has co-taught the class for ten years, and we all take higher education and learning seriously. Currently two of the authors have collaborated as co-instructors for four of the last five years. Small grants from the STEM Initiative at the college have supported the three of us in developing and assessing PHSC. We have attempted to resolve the dilemma of teaching an upper-level physical science course for underprepared, uninterested students by focusing on the nature of science with a degree of intellectual challenge appropriate for an upper level course.

Our public liberal arts college is located in a rural area of the Southeastern United States. With 6,000 undergraduates, it attracts high achieving students who are interested in the intimate atmosphere and close connections between faculty and students for which we are known.

Data Collection and Analysis

Data corpus. The main source of data consists of student work collected over three years: a midterm used in 2011 and 2012 which consisted of the same questions, although differing in the way it was administered to students; photographs and originals of various posters and inscriptions produced by individuals, student groups and the whole class; notes written on the classroom Smartboard by instructors, and whole group inscriptions produced by students over the course of Science Talks; blog posts on the nature of science; journal entries to various prompts including items taken from the VNOS; laboratory reports by students. In all several hundred pieces of student work have been preserved. Photographs of students conducting investigations, especially of whole class collaborative projects such as analyzing data from moon journals kept by each student. We were able to video record one science talk lasting approximately one hour, transcribing portions of the video.

For the last five iterations of the course, instructors met on a regular basis to plan and assess students' progress. We took notes during some of these meetings. For the last two years, two of us met weekly during the semester for two hours or more, taking detailed notes of our observations of students' progress and pondering how to proceed.

In 2011 and 2012 we administered a customized version of the Student Assessment of their Learning Gains (SALG) (Seymour et al. 2000). We were particularly interested in students' responses to questions about which activities and assignments they felt led to learning gains.

Anonymity. All names of students are pseudonyms.

Data analysis. Our research falls into the category of qualitative case study with multiple data sources. The SALG results are quantitative, analyzed using simple descriptive statistics, and used to triangulate with qualitative data.

Texts written by students that were used in the study were compiled and sorted into high, medium and low quality of understanding. Frequencies of these responses were not tabulated, but were correlated with analysis of participation in Science Talks. The Science Talks were analyzed from instructors' notes, the Smartboard inscriptions, and photographs of inscriptions on poster paper.

Portions of the one-hour Science Talk video were transcribed. This recording is of generally poor quality, as only a few portions reflect the enthusiasm and spontaneity that marked other occasions; it occurred on the day of the final when students were fatigued from completing assignments in the 18 hours of coursework in which they were enrolled. The students showed generosity and good will in agreeing to participate in a research study under these circumstances, necessitated by delays in approval by the Institutional Review Board.

The rationale for this methodology is the clear emergence of the Science Talks as the organizing principle of our course. We provide a narrative inquiry (Clandinin & Connelly 2004)—a story of our students' growth as scientific thinkers and our growth as instructors. As qualitative researchers, we argue the goals of qualitative and narrative inquiry are not generalizability and reliability, but apparency, verisimilitude and transferability (Connelly & Clandinin 1990).

Objectivity/subjectivity. Our analysis attempts to achieve what Sandra Harding calls "strong" (1998, p. 18), rather than absolute, objectivity. We have attempted to make our own position during data collection as explicit as possible, allowing the reader to judge the reasonableness of our account and conclusions. For this reason, where appropriate we have chosen to use the first-person plural rather than preserving a fiction of detached invisibility. As busy college professors managing an overload of demands on our time, our data sample began as one of convenience. As we began to sense that something important could be occurring in PHSC, we began to plan more intentionally what data we could collect that would allow us to investigate more deeply and systematically. We have triangulated recollections and hurried notes with reference to the data, especially that embodied in the transcriptions we analyze.

Science Talks in PHSC

We began thinking about Rosebery & Warren's (2008) concept of science talks toward the end of the 2010 iteration of the course. We will analyze in detail three Science Talks—one each from 2010, 2011 and 2012. Over these three years we went from a tentative, spur-of-the-moment trial with pleasing results, to a more intentional use of the Science Talk, to the incorporation of a focus on creating public inscriptions by consensus.

2010. What is Inquiry?

Narrative. On this evening, Richards explained the culminating inquiry lesson assignment to the class. The students said they were unsure as to what inquiry meant. She asked Deneroff to talk with the students about what inquiry teaching is. Her mind raced as she thought about finding a way not to lecture. “How about if I gave you a lecture on how to teach through inquiry?” she asked the class, trying to buy time. “That would be an oxymoron,” someone said.

Deneroff decided on the spur of the moment to see what would happen if we tried out a Science Talk, and hoped it would not be too boring or tedious. Class had already been going on for an hour or two, with much more professor talk than usual. Deneroff worried silently, “Oh no, more talk. Will they stand for it?”

Deneroff posed the question, “Is hands-on the same as inquiry? Can something be inquiry without being hands on?” Her goal was for students to develop a public, shared understanding that inquiry is a way of looking at the world.

Several students dutifully offered opinions; Michael caught Deneroff’s attention by saying, “It’s like what we did the first day of class” (when students wrote and shared science learning autobiographies). Deneroff didn’t know where it might go, but had an instinct that this might be a valuable contribution. She did not fully understand what he meant, and asked whether everyone had understood Michael’s idea. As he elaborated, it became clear that what he was talking about was important. Others picked up on Michael’s conversational thread, and the discussion became a way for the class to look back over the semester and start making sense of what had been to some degree, disconnected episodes of hands-on activities and laboratory investigations. Deneroff and Richards stayed out of the conversation and let the students talk.

After about 20 minutes Deneroff felt it was right to introduce the idea she wanted to get on the table. “So I’ll give you my opinion of what inquiry is—it’s a very broad definition.” Anna jumped up and got ready to write the official definition on the board—at last the professor was going to provide the right answer. “I think inquiry is the position that the facts of science are the result of previously asked questions.” Deneroff actually wanted to use the word “stance,” but thought it might be too much jargon, one of those split-second decisions teaching requires. In spite of the somewhat awkward phrasing, the class animatedly talked about what that might mean.

During the course of the conversation that followed, one of the students brought up a previous discussion, from earlier in the semester, about why the news that Pluto is no longer being classified as a planet had been so very upsetting to many in the class. Deneroff stepped in. “What is the question to which ‘Pluto is a planet’ would be the answer?” Students said things like, “What is it?” “What do you think Clyde Tombaugh was asking when he proposed Pluto as a planet? I wonder whether, if the idea that Pluto is a planet had been presented to you when you were young as the answer to a question, whether you would now be so upset?” There was a generalized murmur of “No.”

Analysis. One of the principles of Science Talk set out by Rosebery and Warren is that students are always trying to make sense (2006). While such a statement sounds good in theory, what are college science instructors supposed to do when students make incorrect, inaccurate or seemingly off-topic statements in class? Michael’s vague contribution, “It’s like what we did the first day of class,” could easily have been dismissed. In fact, it was not picked up by the other students, which is why Deneroff intervened in the conversation and asked Michael to say more.

We understand this as an appropriate role for the instructor during Science Talk, to use her authority so that students together fully explore their own ideas.

Michael's idea, that the science autobiography activity activated the prior knowledge students brought to the class and was a part of the inquiry process, was in fact a wonderful connection to make. It led to an extended discussion of the important ideas that had emerged in PHSC over the course of the semester. Because of the expansiveness of the discussion, students were able to understand inquiry lesson planning through their own lived experiences and had the opportunity to see their own ideas as valuable. The social interactions in the class mediated the joint (collective) construction of individuals as learners and thinkers about inquiry teaching, in SPT terms, identity.

We understand the Science Talk to be an example of what Dorothy Holland (2001) called, "Vygotskian semiotic bootstrapping" (p. 56), a bit of a mouthful. We are all familiar with the admonition to "pull oneself up by the bootstraps." The Science Talk became an opportunity for a collection of individuals who did *not know* what inquiry teaching means to use the meaning of words (semiotics) to engage in dialogue that mediated new knowledge. Because Michael was encouraged by the instructor to voice his ideas about the role of prior knowledge in inquiry, the class had the opportunity to construct knowledge.

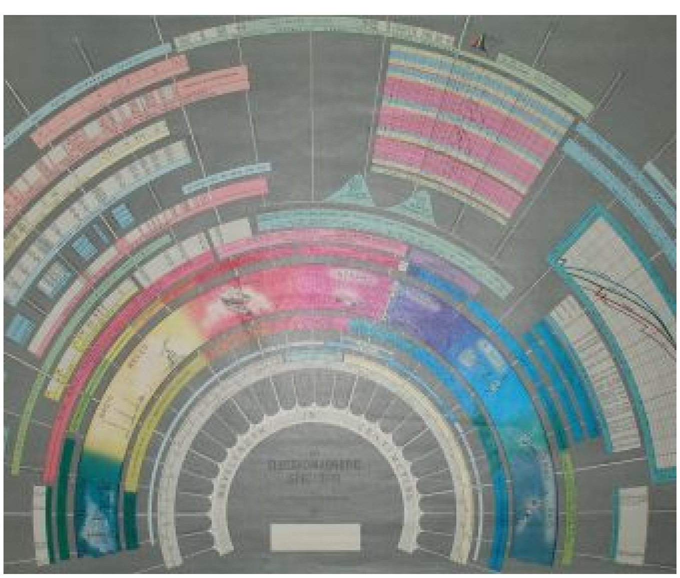
2011. What is the Connection Between Light and Atoms?

Preparation for the Science Talk. In 2011 we more intentionally planned to incorporate the Science Talk model into our teaching. Rosebery and Warren (2006) described how teachers facilitated Science Talks with young children after the class had engaged in extended hands-on, inquiry activities over weeks. It is necessary that the students have a rich store of experiences that will allow consideration of complex ideas and explanations.

Our instructional goal was that students understand that electromagnetic radiation occurs when electrons move from a higher to a lower energy level, and that the wavelength of light emitted is equivalent to the energy difference between them, as described by the formula $E = h\nu$. (We did not actually introduce Planck's constant, which in retrospect was probably a mistake.) We had noted in previous years that inviting students to consider evidence for the development of atomic theory resulted in a disappointing tendency for them to memorize experiments, such as Thompson's and Rutherford's, even to be able to regurgitate the results of classic experiments without being able to explain why these results supported a particular model of the atom. We wanted students to understand that a major impetus for the quantum mechanical model of the atom was the puzzling observation of the emission spectrum of hydrogen.

In order to provide a rich set of experiences with light, we obtained a class set of inexpensive diffraction grating spectacles and went with students on a "Light Tour of Collegetown." We asked them to keep notes about what they saw and what questions they had about their observations. We came back to the lab and students then used the diffraction grating glasses to observe emission spectra of gases using gas discharge tubes.

The following week, we put together a set of ten stations about light with simple activities. One of the stations was an out-of-print diagram of the electromagnetic spectrum from Bell Laboratories, which eventually disappeared from the classroom wall where we had hung it.



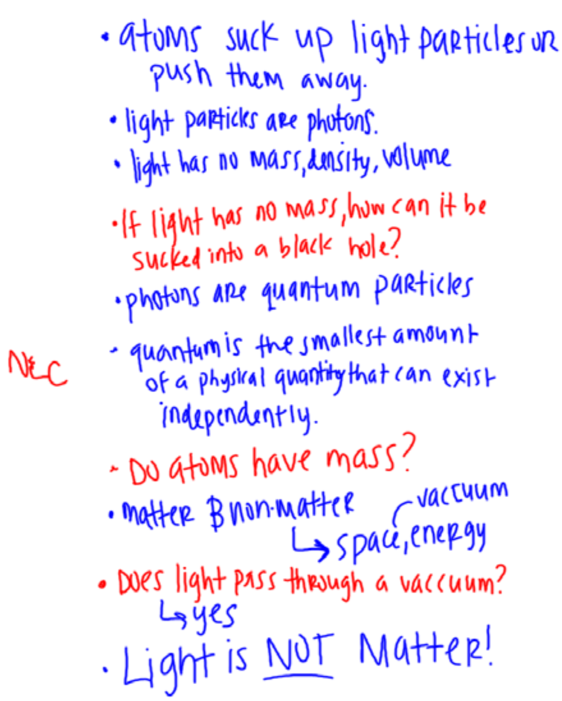
This scientific inscription was rich with information, and at this station students were asked to make observations and ask questions about it. The chart at left is similar in shape and complexity. Other stations included a PhET simulation of color mixing with light, “Seeing Colors;” investigation with pinhole viewers; the PhET simulation “Models of the Hydrogen Atom;” spray bottles with metal chloride salts to do flame tests within the fume hood; a transformer and gas discharge tubes so that students could experiment on their own with emission spectra; a station set up so a roll of Scotch tape could be observed generating ozone from x-rays when the tape was pulled quickly off the roll; a pencil sitting in a half cup of water; colored pictures observed through different filters; and colored filters for open-ended investigations.

We reconvened in the classroom and announced we would be having a Science Talk. Students were to conduct the conversation without the intervention of the professors. We posed the question: “What is the relationship between atoms and light?” This was followed by a long, long silence of perhaps a minute. A student finally said, “I think it’s when photons get caught. That’s when you see light. What you see is light glowing.” Referring to the light tour, someone asked, “Is that why the purple light is closer to the source?” Someone said that purple light has a longer wavelength. Red light has a short wavelength. There seemed to be a general expression of agreement.

One of the students finally said, “No, it is the opposite. It’s ROYGBIV.” Two people got out of their seats and went up to the chart of the electromagnetic spectrum on the wall, and pointed out that purple light has the shortest wavelength. Justin, who was acknowledged as knowledgeable about science by most of the class, proposed that the purple was hotter because it was closer to the light, and therefore had more energy. Justin drew some ladders showing that the electrons in the atoms would liberate light of different colors.

We believed Justin's explanation came from his making connections between the flame tests and the spectra seen through the diffraction gratings. In the ensuing conversation none of the students brought up the observations of the gas emission spectra.

Even though the students got "stuck" on purple light, the conversation eventually ranged widely and students seemed to be working through and making sense of ideas from several weeks of investigations and readings they had done for homework. Students took an active role in running the conversation and several at a time went to the front of the class and drew or wrote on the board. Figure 2 is a Smartboard record of some of the conversation made by Carlotta. It



shows a progression of ideas and questions that demonstrate students were grappling with a range of facts that had not yet become theory. During the Science Talk which lasted for more than an hour, almost everybody in the class said something. Tom, a student who in previous classes had been generally unengaged and looked bored and restless, made several good connections and came to the front of the class to write on the Smartboard.

The students, although they never got to an explanation of the connection between atoms and light and had to be told, asked rather profound questions that showed evidence of deep thought and attempts to make meaningful explanations.

Previously RW pulled Richards aside during the laboratory station event and asked how the eyes differentiate color. After talking with him, Richards felt the essence of his question was, “How can we tell that the light source is emitting the color of light that it is emitting, other than what our eyes tell us we see?” This question brought her up short: As a chemist, she takes for granted the instrumentation she uses to extend the senses, for example not questioning that she is “seeing” with the mass spectrometer.

RW brought the issue up again in the Science Talk: How do we know that what we were seeing at the light sources was what was really going on? Richards traced this back to the light tour, when the class entered the local pool hall where there were numerous neon, incandescent and fluorescent light sources. Some did emit the full spectrum and some did not. RW was curious about why that was so. Of all the students, RW probably came closest to getting at white light being composed of the full spectrum.

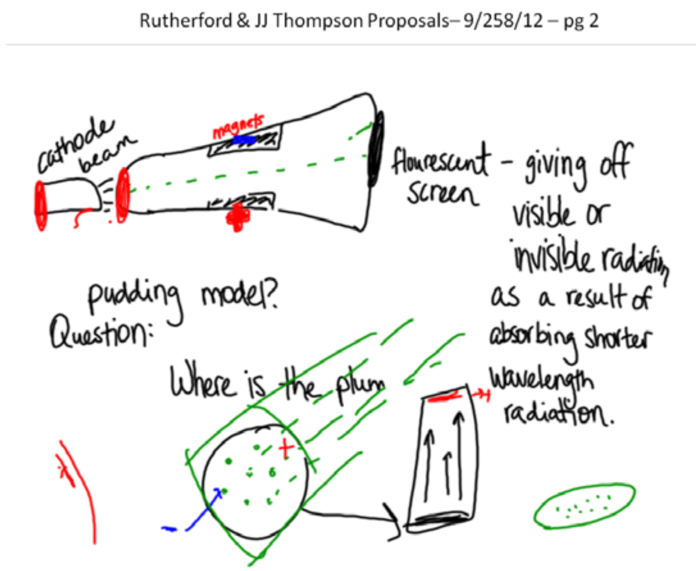
Our inexperience with Science Talk left questions such as RW’s unexplored. Richards reflects, “I didn’t understand Science Talk, so I didn’t know about the power of that type of facilitation where everybody is just hashing it out. I was fascinated by them having an opportunity, without our input, to really think deeply about what they know. They knew a lot. I just don’t know if they knew how to pull it together well. Several times we [Richards and Deneroff] said, we’re just going to have to tell them.” We eventually did.

In retrospect, it was naïve of us to think that students would take the experiments, observations and theories of thinkers from Dalton through Heisenberg and come up with a grand theory on their own. On the other hand, because we asked them to do so, they did show evidence of learning what is perhaps the essence of scientific investigation: Macroscopic effects cannot be explained with macroscopic knowledge. This is why we investigate and conduct experiments, because the explanation for phenomena ultimately lies hidden.

Because of their participation in Science Talks, our students came to understand what it means that "scientists don't know the answer" when they begin to look at their data. Our withholding of the correct answers facilitated their experiencing more authentic science than if they had done cookbook labs and then moved on to the next topic. Moreover, Science Talk introduced pre-service teacher candidates to a way of teaching science that looks beyond correct answers on a test.

2012. Where is the Plum Pudding?

Narrative. Taking some of the right and some of the wrong lessons from our experience with Science Talk in 2011, we planned the 2012 iteration to focus more on talk and less on activities. In 2012, forcing students to hash out their understandings publicly led us to see that most students skillfully and confidently repeated superficial answers which fell apart when we probed for further explanation. For example, in a Science Talk a group of students described J.J. Thompson's cathode ray investigations very competently. They showed the class a YouTube video on his experiments. They drew an inscription of the experimental set-up and asserted that the experiment demonstrated that there was a separation of positive and negative charges within the atom. (See following figure.)



However, as the Science Talk progressed, talk turned to the magnets at the sides of the cathode ray tube. Someone claimed that the magnets were the source of the charged beam noted by Thompson. This statement was agreed to by others, and went unchallenged. The students appeared satisfied that they had demonstrated understanding of the experimental evidence for the plum pudding model, seemingly untroubled by the exact role of the magnets.

At this point, Deneroff looked at inscription on the Smartboard screen, and was struck by something she had never particularly thought about before: How had Thompson made the leap from the cathode ray tube to the atom? What part of the cathode ray tube was analogous to Thompson’s plum pudding? She asked the class, “In your drawing, where is the plum pudding?” This question made its way onto the Smartboard, now partly obscured by a later attempt to represent the plum pudding as the cathode with dots for the electrons. It took several minutes for the class to understand what Deneroff was asking. After talking it through, students decided the cathode itself had to be the atom. Thinking more precisely, at the direction of students, Richards drew the smaller circle on the bottom right. The smaller circle was an expanded version of one of the “dots” on the cathode. The meaning of the dots on the larger circle was transformed, so that now each of them represented an atom. In the magnified atom, the dots now represented electrons.

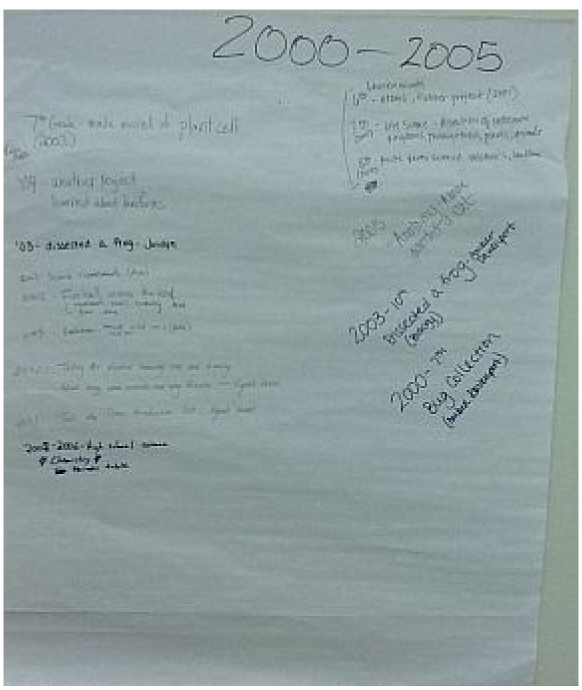
Analysis. In the 2012 iteration of PHSC, we thought much more carefully about using Science Talk as a vehicle for understanding content. We decided on a knowledge progression for understanding the development atomic theory, and relied much more heavily on asking students to research Internet sources on the history of physics. On their own, students found online videos which provided them with insights into Thompson, Rutherford and Bohr. We were more focused in our questions, shying away from the broad prompt, “What is the connection between atoms and light?” Instead we focused Science Talks on the connection between experimental data and the historical development of models of the atom.

We were modestly successful in reaching this goal. In 2011 we had given students a midterm consisting of statements about various ideas that emerged in the history of atomic theory. They were prompted to provide evidence from the class activities and labs which supported the statements. The scores on this examination were very low, with only 5 of 19 receiving a passing score of 70 or higher. In 2012 we gave students the same statements and, in a slightly different format, the same prompts. Students were able to connect the evidence with the propositions, and all but one of 17 passed. There are too many variables for us to claim that the more focused Science Talks were the decisive factor in the improved performance, however it is worth further investigation, since there is a growing body of research in science education that participating in argumentation scaffolds increased conceptual knowledge more effectively than other pedagogies (Osborne et al., 2013).

On the other hand, narrowing the Science Talks, shutting down the wide-ranging explorations, and discarding activities which did not obviously contribute to the knowledge progression seems to have taken away some of the thrill of discovery for both professors and students. Moreover, our sense is that the more open-ended discussions, which arose from deeper and more fundamental connections with students' lived experiences, were likely more helpful in allowing students together to construct narratives about science which were not present prior to their taking PHSC.

Conclusion

One of the astonishing moments of insight for the authors came in during the first class meeting of 2011. The figure below is a photo of one of the posters on which students had written what they remembered of their science experiences. As the class gathered round, Deneroff read off the entries. "So it looks like a lot of people dissected frogs in 2003. Why was that science?" The students seemed stunned by the question and there was a long pause. After some discussion, we came to the conclusion they thought it was science because they had done it in science class. The students shrugged off this nonsensical question which did not have meaning in their experiences as learners. The enormity of the task confronting us, of introducing a world view which was not part of our students' repertoire of identities was revealed in that instant.



After a decade of struggle to understand how to engage non-majors in the intellectual processes of science, we have begun to investigate the origins of their knowledge and develop a theoretical framework with the power to guide us in making substantive changes in the ways we design our course. We do this out of respect for our students, having known them as diligent and willing to try to accomplish what we ask of them. We have come to see for ourselves that the practice of school science does not provide students with the identity of “knower of science,” and that the task of our instruction is to serve as brokers (Wenger, 2008) between the community of scientists and the community of educated lay persons.

The SPT construct of identity as lived, embodied, mutual understandings of what people are doing when they interact in social spaces allows us to design a learning environment that facilitates students’ deep learning. As a consequence we have come to see conversation as our principal tool for instruction. Conversation implies an equality of status between the parties. Although as instructors we are more knowledgeable about the concepts of our course, only the students can articulate their prior experiences and the conclusions they have drawn from them.

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