Transferring and Constructing Knowledge: Designing an STC Based Teacher Workshop

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ABSTRACT

The National Science Foundation Science and Technology Center at the University of Arizona sponsored a two-week workshop for science teachers. The overall goal of the workshop was to increase participants' hydrologic literacy by teaching issues and concepts concerning semi-arid hydrology in the Southwest, as defined by educators and scientists associated with Sustainability of semi-Arid Hydrology and Riparian Areas (SAHRA). It was designed to show teachers how to teach science content using a "science as inquiry" approach.There were three phases to the workshop: developing a need to know, acquiring conceptual knowledge, and applying newly acquired knowledge. Evaluations showed that teachers felt the pedagogical discussions following each activity were as important as the content they learned, and they recommended that more workshop time be spent for these conversations. These findings support the efficacy of the workshop design and they suggest revisions for future workshops.

Keywords: Education - workshops; education – teachers, inquiry, problem-based learning, hydrology.

INTRODUCTION

The goal of the *Benchmarks for Scientific Literacy* (*Benchmarks*) (American Association for the Advancement of Science [AAAS], 1993) and the *National Science Education Standards* (*NSES*) (National Research Council [NRC], 1996) is to increase the scientific literacy of students. Both documents stress that students must learn scientific content knowledge, the nature and characteristics of scientific knowledge, and the skills needed to acquire and evaluate scientific knowledge. This knowledge is used to make informed personal and professional decisions, to participate in civic and cultural matters, and to increase economic productivity. Both sets of standards exist as guidelines for teachers that describe what science content to teach to students and how to teach that content. One way teachers can develop a deeper comprehension of science content is through workshops sponsored by universities and other science-based institutions.

A National Science Foundation funded Science-Technology Center (STC) at the University of Arizona known as Sustainability of semi-Arid Hydrology and Riparian Areas (SAHRA) has the main goal of acquiring new knowledge about semi-arid hydrology and disseminating that knowledge to diverse stakeholders, such as policy makers and the general public. The educational component of the STC has the additional goal of building an "understanding of key water issues into K-16 science education and to promote hydrologic literacy throughout the population that makes water-use and related political decisions" (SAHRA, 2000). With schools being held accountable to state mandated science education standards, the faculty and staff in SAHRA needed to develop a set of hydrologic literacy standards that were in alignment with state and national standards. These hydrologic literacy standards (See Table 1) originated from a survey of SAHRA hydrologists who were asked to determine what hydrology content knowledge they considered important for K-12 students to learn. The identified concepts were further developed through a review and comment process with educators, science educators, water educators, scientists and hydrologists, and refined through consensus and then cross referenced with the *Arizona State Science Academic Standards* (Arizona Department of Education [ADE], 1997), the *Benchmarks* and the *NSES* (See Table 2).

One of the programs to disseminate and educate teachers about hydrologic literacy was a two-week long professional development workshop for science teachers called "Hydrologic Literacy in the Secondary Classroom", which is the subject of this article. The purpose of the workshop was for teachers to learn and apply hydrological concepts through inquiry and Problem-Based Learning (PBL) teaching techniques (Uyeda, et al., 2002). Workshop instructors designed, introduced, and modeled inquiry and PBL methods to participants through activities where teachers assumed the role of students. The activities were followed by discussions focused on adaptation and implementation of these techniques in the teachers' classrooms. This routine ensured that the workshop focused on science content knowledge and pedagogical knowledge.

TWO KEY CONSIDERATIONS TO WORKSHOP DESIGN

Knowledge acquisition through constructivism is a key element of effective professional development workshop design (Loucks-Horsley, et al., 1998). Constructivism refers to the process in which a person makes sense of

Know various processes and components of the water cycle. Examples of this standard would include, but are not limited to, a discussion of: Evaporation Condensation Run-off Groundwater
Know that water is essential to life. Examples of this standard would include, but are not limited to, an ability to describe how water is essential to organisms and ecosystems in terms of: Growth Development Well-being
Know that there are natural effects of water on the environment. Examples of this standard would include, but are not limited to, a discussion of: Adequate water Drought Flood Erosion
Know the sources of water available to their community, how the sources are accessed and what limitations exist. Examples of this standard would include, but are not limited to: Groundwater Watersheds Reclaimed water Transported water
Know how water contributes to the quality of human life. Examples of this standard would include, but are not limited to, an understanding of water use in: Recreation Industry Agriculture Water power
Know how humans can impact the quantity and quality of water resources. Examples of this standard would include, but are not limited to, an understanding of the various types of: Pollution Excess water use Disruption of water pathways (i.e. dams, human constructed reservoir)

Table 1. SAHRA hydrologic literacy standards.

Arizona State Academic Standards: Science 6SC-E6. Describe the distribution and circulation of the world's water through ocean currents, glaciers, rivers, ground water and atmosphere 6SC-P5. Identify, investigate and predict the factors that influence the quality of water and how it can be reused, recycled and conserved 6SC-P6. Identify and compare the interactions between water and other earth systems including the biosphere, lithosphere and atmosphere
National Science Education Standards Water, which covers the majority of the earth's surface, circulates through the crust, oceans, and atmosphere in what is known as the "water cycle." Water evaporates from the earth's surface, rises and cools as it moves to higher elevations, condenses as rain or snow, and falls to the surface where it collects in lakes, oceans, soil, and in rocks underground. Water is a solvent. As it passes through the water cycle it dissolves minerals and gases and carries them to the oceans.
Benchmarks for Science Literacy The cycling of water in and out of the atmosphere plays an important role in determining climate patterns. Water evaporates from the surface of the earth, rises and cools, condenses into rain or snow, and falls again to the surface. The water falling on land collects in rivers and lakes, soil and porous layers of rock, and much of it flows back to the ocean. Fresh water, limited in supply, is essential for life and also for industrial processes. Rivers, lakes and groundwater can be depleted or polluted, becoming unavailable or unsuitable for life. Weather (in the short run) and climate (in the long run, involve the transfer of energy in and out of the atmosphere. Solar radiation heats the land masses, oceans and air. Transfer of heat energy at the boundaries between the atmosphere, the land masses and the oceans results in layers of different temperatures and densities in both the ocean and atmosphere. The action of gravitational force on regions of different densities causes them to rise or fall – and such circulation, influenced by the rotation of the earth, produces winds and ocean currents.

Table 2. State and national subject matter standards taught in the workshop.

incoming information. Specifically, a learner encounters a new experience, which causes disequilibrium in their current knowledge base. The learner then compares the new experience to prior knowledge, and if the new concept is plausible, intelligible, and fruitful, the new concept may be accommodated into the learner's knowledge base (Posner, et al., 1982). More recently, the role of dialogue and conversation have been viewed as an important component in the construction of knowledge (Fosnot, 1996). Teachers, like students, construct their science knowledge and pedagogical knowledge. Recognizing that teachers do construct their knowledge is essential in the design and implementation of a workshop, institute, lesson study or other professional development endeavor (Loucks-Horsley, et al., 1998)

Another key element for workshop design is devoting time for participants to purposefully reflect on the process of learning, and the content that is learned. (Fullan, 2001, Loucks-Horsley et al., 1998). Reflection can be defined as thinking about actions that exist in the event and examining the knowledge and beliefs that drive such actions (Schön, 1987). Reflection allows teachers to understand the rationale behind their instruction, challenges or reinforces their existing notions regarding instruction, and fosters new knowledge and beliefs that support actions, procedures and strategies in their classrooms. Richardson (1996) supports the importance of reflection when she concluded that reflecting on one's practice directly impacts beliefs and practices, and moves teachers towards more constructivist approaches. Clearly, if teachers are going to learn new skills, knowledge, and develop new beliefs, reflection needs to be integrated into any professional development program (Loucks-Horsley, et al. 1998).

WORKSHOP CONTEXT

The first workshop was held at the Department of Hydrology on the University of Arizona (UA) campus in Tucson, Arizona in mid July 2001. The second workshop

I: Based on the presentation we have just seen, what are some of the pressing water issues for this community? P: How much water there is, water use, CAP water, radon and arsenic in drinking water, water supply and city growth….
Participants generate issues list
I: OK, take this list of issues and look for what they may have in common and place the issues into categories. For example, CAP water and arsenic in drinking water are both water quality issues and can be placed in that category. There will be some overlap, and your group will need to decide which category is best for the issue. When we come back together as a group, be ready to tell us how you classified the issues and the reasons behind your choices. Is the task clear? Go to it!
I: Let's start with this group here. Which issues have things in common? P: Well , we placed how much water, recharge, where the water comes from, wells, growth and water supply in a category called "groundwater". I: Why did you do that? P: We heard from the presentation that Tucson gets its water from an underground water supply and all these issues are connected to that. I: What do you mean by "recharge"? P: Well, that's what it's called when water soaks into the ground. I would guess that the water then goes to, to our water supply. I: Do any of the other groups agree, disagree or have anything to add to this issues category? P: I would add the term aquifer to the list. P: How is the word aquifer an issue? P: An aquifer is what the underground water source is called. P: So how is a label an issue? I: Is there another way to think about aquifers that may help it become an issue? P: Well, the presentation talked about a drop in the level of the aquifer, so I guess that would be the issue. P: Right, because as we use groundwater and with this drought, the groundwater isn't refilled, so the level drops. That's definitely a part of this category. I: Is groundwater the only major category? What about this group? Can these other issues be classified in another category?
Discussion continues until all issues are clarified and in categories.
I: So it appears that all these issues can be categorized into three common themes: water quality, groundwater and water supply management. We will be looking into these themes during this workshop.

Table 3. "Developing a Need to Know" dialoge (I=instructors, P=Participants).

was held at the New Mexico Institute of Mining and Technology (NMT) in Socorro, New Mexico in late July 2001. Three teachers participated in the UA workshop, and five teachers participated in the NMT workshop. All the participants were secondary math and science teachers. The low number of participants was due to the voluntary nature of the workshop and the large number of professional development workshops offered during the same time frame, mid and late July. The UA course qualified for graduate credit, and the NMT course was an offering for the Master's for Science Teachers graduate program.

There were two instructors for the course. One instructor, who provided content knowledge expertise, was a local high school science teacher who has been heavily involved with the Department of Hydrology and College of Geosciences at the UA. The other instructor, also a local high school science teacher as well as a graduate student in science education, provided pedagogical knowledge expertise. Both of these teachers were skilled at unifying science content and science as inquiry in their high school classes. There were three UA faculty members involved as advisors for the workshop. One faculty member, a professor in the Department of Hydrology and an assistant director for SAHRA, served as the main administrative liaison and as a content knowledge expert. Another faculty member, a research professor in the College of Agriculture, made available her knowledge of agriculture and computer webpage design. The third faculty member was a professor in the College of Education who supplied expertise on how students learn science, the teaching of science through inquiry, and professional development program design.

There were two workshop goals. The first goal was to increase the hydrologic literacy of participants. The second goal was to instruct teachers in constructivist teaching approaches such as inquiry and problem-solving teaching techniques. To accomplish these goals, the workshop was divided into three phases: (a) developing a need to know, (b) hydrology knowledge base acquisition and (c) application of learned knowledge.

DEVELOPING "A NEED TO KNOW"

The purpose of the first phase was to develop an intrinsic curiosity about hydrology through the exploration of local water issues. In this phase, which took place on the first day of the workshop, teachers were introduced to water issues in the southwest by a local hydrologist. After this presentation, a conversation began with a discussion to construct common themes that interconnected these issues. Issues were elicited from the participants who then classified the issues into categories. Instructors used probing questions to clarify reasoning behind the classification of issues. The discussion continued until there was a consensus amongst the teachers about the classification scheme for the issues (Table 3).

These conversations develop an intrinsic curiosity among the teachers to explore the identified issues and their corresponding science. Examination of the dialogue shows the instructors actively engaged with learners in developing information instead of being the information source. Direct intervention by the instructors was to summarize discussion, provide instructions or to clarify participant language or reasoning through probing questions. To encourage further curiosity, the participants next chose an issue or event from a pre-generated list (e.g., subsidence in local cities, specific water diversion projects, increase in radon and arsenic in groundwater, water purification methods) and gathered information for a short presentation later that day. After teacher presentations, the instructors and the participants discussed questions that came up during research on the topics. These questions were related back to the issues generated earlier in the day to form a content framework for the rest of the workshop. The first day ended with a pedagogical discussion to highlight constructivist teaching methods used to develop learner curiosity.

KNOWLEDGE BASE ACQUISITION

The second phase of the workshop was termed "knowledge base acquisition". In this three-day phase, teachers were introduced to hydrologic content through "science as inquiry" (NRC, 1996) Concepts to be learned were about water quality and the interrelationship between surface and groundwater. Participants gathered data from simple water quality tests in the laboratory and investigations using groundwater models and presented their findings to the rest of the class. Teachers were assigned readings every night during the first week. These readings provided background for the next day's work and were often technical reports from governmental agencies such as the United States Geological Survey. Readings about local water issues were collected for each workshop location. Similar to the first phase, the instructors would lead discussions designed to develop concepts through analysis and discussion of readings and collected data and observations as well as conversations about pedagogy used for inquiry.

Participants experienced "science as inquiry" during this phase of the workshop. In the UA workshop, a technique known as Search-Solve-Create-Share (SSCS) (Pizzini, et al., 1989) was used. This pedagogy is a complex and powerful technique that is student-centered and open-ended, allowing students to learn content, the nature of science, and about the "science as inquiry" process. However, SSCS requires more time to implement than was allotted in the NMT workshop schedule.

In response to this difficulty, two inquiry techniques requiring less time were introduced to the NMT participants. Water quality was investigated with the descriptive learning cycle (Lawson, 2001), an approach where students look inductively for patterns in collected data. The relationship between surface and groundwater was examined using the 5-E learning cycle (Engage, Explore, Explain, Extend and Evaluate) (Bybee, 1997). Both of these instructional approaches are sound introductions to "science as inquiry," and simple models that teachers can use to adapt their current curriculum.

APPLICATION OF LEARNED KNOWLEDGE

The third phase of the workshop was designed to allow participants to apply new knowledge as well as learning additional information and concepts. This phase was accomplished using a teaching technique called PBL (Barrows, 1994; Gallagher, et al., 1995; Neufeld and Barrows, 1974). The focus of PBL is for students to learn how to resolve multi-dimensional scenarios found in the real world. These scenarios are typically based on actual situations using genuine data and evidence. Problems have several characteristics that characterize them as PBL problems: (a) a realistic role for students, (b) an ill-structured task to resolve, (c) multiple resolutions to the task, (d) use of prior knowledge, (d) acquisition of new knowledge, (e) critical review of knowledge in the context of the problem, and (e) an authentic assessment (Barrows, 1994). Students are required to develop the best resolution to the problem, based on available evidence.

For this workshop, participants assumed the role of committee members appointed to manage water for the Tucson Active Management Area (TAMA). TAMA is a water management district created through the Arizona Groundwater Act of 1980. The PBL problem was divided into two sections. The first section took place in 1980, and the committee was to develop and present the first water management plan for the TAMA to fictitious representatives from the state water regulatory agency. The second section of the problem moved participants forward in time to 2000. The task of the committee was to evaluate, critique and modify the initial plan based on data collected from 1980 to 2000. Again teachers were asked to present their findings and recommendations for plan modification to the same representatives of the same state agency.

- What went well for me today?
- What further questions do I have?

Table 4. Daily evaluation questions.

EVALUATION AND REFLECTION

The course was evaluated through use of daily evaluations and a final summative questionnaire. Loucks-Horsley, et al. (1998) notes that constant assessment of how the participants are progressing through a workshop is crucial to fulfilling participant needs. The purpose of the daily evaluations was to focus on daily success and progress, and to address pressing questions of the participants that were related to the course. The daily evaluation was given to participants at the end of the day (Table 4), while instructors of the course took notes on the participants' activities and assessed the progress of the participants based upon an examination of their notes.

Participant comments on the daily evaluation ranged from personal to social to professional. Personal comments tended to focus around content knowledge, and included comments such as "I realize how little I understand about water," "Is the soil profile closely related to the water profile?", and "I want to learn more about water quality." Remarks concerning social success centered around how well groups collaborated on various activities, and included: "my teammates really helped me understand the experiment", and "I like working as a collaborative group. Multiple heads thinking about how's and why's are better than one!" Each point raised on the daily evaluation was addressed in the following class in order to help teachers negotiate some of their stated concerns.

The analyzed notes of the instructors revealed that participants struggled with equipment issues, pedagogical processes, and curricular discussions. A participant asked, for example, during one discussion: "do you have students present their findings that same day they do the activity? Time seems to be a constraint." For the participants in this workshop, the issue of time was consistently raised as a problem with inquiry. Another common item for discussion was locating equipment. Several teachers commented on the value of learning about water, but the materials to conduct such investigations would be difficult to acquire without adequate funding. The concerns raised by participants, which were collected by the instructors, were much more difficult to address. Possible solutions were discussed and suggested during the workshop.

A summative survey was administered to the teachers to evaluate their experience in the summer workshop (Loucks-Horsley, et al.,1998). The survey was a questionnaire with short-answer questions that were answered by teachers at the end of the course and sent to the College of Education advisor. Questions were designed to evaluate usefulness of the program to

- How did this course compare to your expectations for the course? Please explain.
- What did you find beneficial about the course as a science teacher? Please explain.
- What would you suggest be changed in the course? Please explain.
- How does this course compare to other courses offered in science and engineering that you have taken?
- If you implement any of the content and/or teaching methods presented in this program, how do you think you will do it?
- What support would you need for implementation?

Table 5.Summative survey questions.

participants and determine what additional support may be needed (Table 5).

Many of the survey question answers were very positive. Participants liked the teaching techniques used in the workshop, calling them great, exciting, and frustrating but rewarding. They liked the hands-on and student-centered characteristics of the teaching techniques presented. Teachers liked the applicability of the teaching methods to classroom situations.

Negative comments centered on the individual workload and time required of each teacher; however, one colleague seemed to relish the fact that they "were definitely treated like graduate students with homework loads included. Now that it is over, I actually KNOW I learned something from this class". Another negative comment recognized some erroneous planning. Two of the activities, the field trip and a lesson in using the spreadsheet software Excel were deemed to be irrelevant and out of context. Teachers commented that both activities would make more sense if they had requested the activities in the process of working on their PBL activity. Related to the previous statement, the New Mexico workshop participants asserted that the program curriculum should have been focused around local water issues instead of Tucson water issues to increase interest and participation.

The most beneficial aspect of the workshop was the unification of pedagogy and content through a "science as inquiry" framework. The need for discussions about content and pedagogical implementation was a crucial aspect to the course. Teachers expressed a desire for these discussions and appreciated discourse about implementation as seen in the following comments: "I would like more opportunity to 'step back' and look at things from a teacher perspective…," "We produced 5-E lesson plans for our classroom, but more importantly [we] learned about the methods of teaching in this manner …," "I really appreciated the 'teacher's perspective' on how to teach content," and "…the instruction was not only content, but also methodology based. I think that is a good idea – content and how to present it."

WHAT WE LEARNED

There are a few conclusions that emerge from workshop evaluations and discussions with participants. The first conclusion is that a science workshop designed to

Table 6. Pedagogical discussion dialogue (I=Instructors, P=Participants).

I: Now that we've finished our first inquiry activity, let's think about what happened during the activity – what we did and in what order did we do things. So, what did we do first?

P: We tested our water samples.

I: What did we do before we tested water samples?

P: Oh! We talked about our water samples, if they were from wells or municipal water, how they tasted and smelled at different times of year..

I: OK, then?

P: Then we tested our water samples.

I: OK what happened next?

P: Well, we presented our results and you had us examine the results to see if there were any visible patterns in the data, which we found.

I: OK to summarize at this point. We talked about our own water samples, tested our samples and then looked for possible trends in the data which we found…

P: Like the decreasing TDS going from the springs west of Socorro to the Rio Grande.

I: OK good, then what did we do?

P: You gave us some vocabulary about water quality.

P: Which you related to the water testing we just did.

P: We also talked about how some of the processes we defined may work to produce the data we saw.

I: OK After introducing the vocab and having a discussion about content, then what did we do?

P: You gave us some additional supplies and equipment and asked us to conduct our own experiment.

I: what was the experiment based on?

P: Our conclusions from the first activity gave us a question about what happens to solutes as they pass through soil.

P: Then we did our experiment and presented the results.

I: And then?

P: And then we tried to explain our results, using the readings we did and the information given to us earlier today.

I: OK Now, I want you to break up into small groups of three and talk about what happened during the activity in terms of how each step made you feel as a student.

Task prompt is discussed by participants

I: We have a list of the events that took place during the activity. So, what did each step do for you, to you as a student? What did it make you think about?

P: Well, talking about our water samples focused us on water quality.

P: And then testing our own water samples increased our interest as well as teaching us how to use the test kits.

P: Then looking at our own data started us, well me anyway, to think up questions to try and explain the data.

I: OK, this first part of the descriptive learning cycle is called "Exploration" and is designed to do all those things you all mentioned. In addition it was to give you an experience from which to work on. You may have noticed that I tried very hard to not use vocabulary or make possible explanations about the data. I wanted to focus on the experience first. So, what about the next step in the process?

P: At this point, we sat down and you gave us vocabulary.

P: But first, he asked us about what we knew and had us give definitions or explain ourselves when we used vocabulary terms.

I: Exactly. This step in the process is called "Concept Introduction". The key technique here is to use the experience students just shared to build knowledge. Vocabulary and concepts are based on what students did and saw, so it is easier for students to understand technical terms as they have something to relate to them. OK, what about the next step?

P: So then we looked at our data and you guided us through analysis to come up with a general question.

P: Then you told us to come up with a more specific question for us to test.

P: After our experiment we presented our results.

P: Oh! And then we tried to explain trends in our results based on the vocabulary and concepts that we just learned. In when we didn't use a vocabulary term or concept, you got us to recall the appropriate knowledge.

I: Right. More on questions and inquiry later. This part of the cycle is called "Concept Application" and is used to reinforce new learning. But it does so in a way that teachs for understanding. Remember when we discussed understanding as application of knowledge in a new and novel situation? This phase of the descriptive learning cycle fulfills this goal.

explicitly combine science content and inquiry-based pedagogy is deemed beneficial by teachers. Learning new content is not a guarantee that this content will be a part of the participants' science curriculum. Teachers must know how to translate the science concepts learned to appropriate instruction for children, especially their own student populations. To increase chances for teachers to alter practice, workshops must model new pedagogy while teaching new content, and instructors must be very explicit about how new teaching techniques were used to teach new content. In this workshop, both teaching techniques and methods of instruction that used science processes to teach science content were demonstrated and discussed (Loucks-Horsley, et al., 1998).

The second conclusion addresses the importance of a constructivist and reflective orientation during workshops. Throughout the workshop, participants were encouraged to construct their own knowledge about inquiry practice through dialogue with each other and the instructors (Table 6). The opportunity to discuss the practical application of content and pedagogical processes in the classroom is essential as teachers learn new material. Discussions allowed teachers to challenge and refine their current understandings. In addition, reflective periods provided teachers with an opportunity to explore their beliefs about teaching, their ideas about learning and classroom instruction, and their current knowledge base. Such reflections ultimately clarified the practices that some teachers enacted and assisted teachers in building beliefs that are more conducive to "science as inquiry" practice.

THE FUTURE

The summer of 2002 and the academic year of 2002-2003 will see some changes in the workshop based on what was learned from the previous year's implementation and participant evaluations. Pedagogical support for teachers will be made available through electronic communication and classroom visitations. To provide access to equipment and supplies, a loan system will be developed for a limited supply of water quality test kits and groundwater models.

A system to provide additional support for teachers throughout the academic year will be developed. Fullan (2001) asserts that the one-time workshop is not likely to produce any change in teacher practice. On the other hand, Loucks-Horsley, et al (1998) notes that while a one-time workshop may be a good start to learning new content and pedagogy, additional opportunities need to be provided to teachers using a number of different strategies. From participant evaluations, it was evident that our teachers did benefit from this workshop, but that follow-up activities may increase the application of the learned strategies in the teachers' classrooms. Furthermore, additional support may assist teachers in negotiating pedagogical concerns and in finding appropriate equipment and supplies

Finally, effective professional development should have a positive result on students' learning through their teachers. In order to evaluate the helpfulness of this workshop, a program evaluation that measures the impact of the workshop and subsequent support on classroom practice needs to be conceived and put into operation to evaluate program efficacy.

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