Interventions that
Engaged Teachers with Student Instructional Materials in Science

Excerpted from Alonzo, A. C. (2002). Evaluation of a model for supporting the development of elementary school teachers' science content knowledge. ***Proceedings of the Annual International Conference of the Association for the Education of Teachers in Science*****.**

"The professional development model analyzed in this paper supports the development of teachers' science content knowledge by providing the experience of investigating a particular area of science content in an inquiry-based environment. Inquiry science teaching is expected to be improved through both increased content knowledge and teachers' authentic experience of learning science in an inquiry environment. The model is depicted in Figure 1.

Consistent with guidelines for effective professional development (Loucks-Horsley, Stiles, & Hewson, 1996), this model allows teachers to engage with a particular content area in a deep manner, over an extended period of time. Their learning is supported by a teacher-scientist pair who function as facilitators, providing (a) questions to investigate and (b) guidance in conducting and interpreting explorations based on these and the teachers' own questions. In this way, the facilitators model inquiry science pedagogy.

Although the blending of content and pedagogy is useful at any stage of teacher development, this particular model has been designed to address the science content needs of elementary school teachers who have been teaching inquiry-based science in their classrooms and would like to obtain a stronger understanding of the content of a particular curriculum unit. These teachers have, for the most part, a level of expertise characterized by the 'use' of inquiry science materials (NSRC, 1997), and are struggling with how to translate the curriculum units into rich learning experiences for their students. Because the model provides teachers with opportunities to learn about science content directly aligned with that being presented to their students, it is expected that increased content knowledge will be directly applicable in the classroom, enabling teachers to better guide their students' investigations. However, the model contains no explicit connections to the elementary school classroom. In focusing only on teachers' learning of the science content and their experience of learning in an inquiry environment, the model excludes discussion of how this knowledge can be applied to teachers' work with their students.

At its most basic level, this professional development model represents an attempt to interweave content and pedagogy (Post, 1997). It is patterned after the work of Duckworth, Easley, Hawkins, and Henriques (1990), who describe engaging teachers with 'the real subject matter of science' and through this, a consideration of themselves and others as learners. As in the work of Duckworth and her colleagues, the content is adult-level science content related to topics taught in elementary school classrooms, while the pedagogy is inquiry pedagogy, or (in Duckworth's case) constructivist pedagogy. Thus, teachers learn in an environment similar to that which they are expected to create for their own students…
In particular, teachers are given the opportunity to build upon their previous conceptions of the science content by designing their own explorations and constructing their own explanations, with guidance from both a fellow teacher and a scientist.

This paper focuses on a particular implementation of this model, a course entitled Floating & Sinking (Alonzo, Hartney, Linden, Post, & Stewart, 1997). It was designed according to the components of the professional development model described above. The course addresses the science content contained in the Clay Boats unit (Elementary Science Study, 1996), part of the district-wide curriculum for third graders at the schools in this study. The Clay Boats unit engages students in initial explorations of concepts related to floating and sinking, through the construction and testing of boats made out of materials such as clay, foil, and waxed paper. The Floating and Sinking course provides teachers with the opportunity to engage in an in-depth exploration of concepts related to density for a total of 24 hours.

The Floating & Sinking module begins with an elicitation of teachers' prior knowledge and an activity in which they predict and test whether a variety of household objects will float or sink when placed in water. Next, teachers explore the question, 'What variables affect floating and sinking?' This is followed by investigations of both weight and water displacement. Teachers return to the task of predicting floating/sinking behavior by using the results of their previous inquiries to make predictions about mystery cylinders. Next, they consider floating/sinking behavior in liquids other than water. Finally, they rely on all of their investigations to invent a definition of density and explain its role in determining whether an object will float or sink."

Excerpted from Atwood, R. K., Christopher, J.E., McNall, R. (2005). *Elementary teachers' understanding of standards-based light concepts before and after instruction*. Paper presented at the annual meeting of the National Association for Research in Science Teaching, Dallas, TX.

Procedure
"The sample consisted of 72 elementary teachers from rural school districts in three Mid - Atlantic States. During the summer, 2003, each teacher was enrolled in one of three two-week physical science institutes offered through a funded project….

Light Instruction
In order to provide background information necessary to interpret the results, a brief description of the instruction on light is provided. Participants learned about light during intensive, two-week summer institutes in which light was one of four topics addressed. During the five-hour work days, small groups of three teachers engaged in investigations accompanied and followed by interpretive discussions and interpretive writing. Written responses to questions and prompts were routinely defended in conference with an instructor, producing an active learning culture among the instructor, participants, and the curriculum (Duschl & Gitomer, 1991). A whole-class review of light was conducted at the end of the light studies. The source of investigative activities, questions, and other prompts for interpretive discussion and writing was Physics by Inquiry (McDermott, 1996). An examination of these materials reveals that the developers were aware of the most frequently held non-scientific conceptions for each major topic addressed. Further, the developers utilized activities that lead to observations at odds with popular non-scientific conceptions. During study in the institute, participants were pushed repeatedly to construct conceptual models consistent with their observations and to modify a model, when new observations were determined to be inconsistent with it. Using this strategy, some popular non-scientific conceptions were intentionally confronted.

Highlights of the instructional activities follow. Each group was given a small Minimaglite® (2AA battery size) that can be made into an electric 'candle' by removing the cap containing the lens and reflector. The advantage of this feature is that the very small exposed bulb approximates a point source of light. Observations of the light bulb were made by participants with and without a special cap, which was a black ping-pong ball with a few small holes. The ping pong ball cap was placed over the top of the Minimaglite® with the bulb located in the center of the ball. Teachers determined where the eye must be placed to see the bulb when the bulb is on and the room lights are off, as well as when the bulb is off and the room lights are on. In a darkened room, with the special cap attached, participants determined that an invisible light beam could be made observable by placing chalk dust in it. From these investigations the teachers concluded that light travels in a straight line from a source or from an object after being reflected from another source, and that light must enter the eye to be observed. They also were able to predict circumstances in which a light beam could be observed. These principles were subsequently applied in activities that involved light passing through a mask and onto a screen. The hole shapes in the mask, number of point sources, line and surface sources (frosted light bulb) were varied. A few investigations with shadows also were completed.

The study of reflection of light began with basic exploratory experiments using a narrow light beam directed across a piece of butcher paper to strike a plane mirror and reflect back onto the butcher paper. The participants were able to observe and trace the path of light and ultimately conclude that the angle of the incoming beam of light and the mirror form an angle which is equal to the angle of the outgoing beam of light and the mirror (angles are measured as those that are less than 90 degrees.) The diffuse reflection of light from construction paper was also observed, as well as light reflecting from a glossy book cover. The latter shows traits of both the specular reflection of mirrors and the diffuse reflection of construction paper. Ray tracing and observations were used to determine the range of positions and directions one must look for viewing the image of an object in a plane mirror. The parallax phenomena was introduced and used to locate a second nail behind a mirror at the image of a first nail located in front of the mirror. Ray tracing was used to confirm the image location. Ray tracing was also used to explore the path of light traveling from a source to the mirror and ultimately to an observer's eye in image formation.

The study of refraction of light began with basic exploratory experiments. A narrow light beam was directed across a piece of butcher paper to strike a round beaker and later a cubic container. These activities were repeated sequentially with plain water, water containing a little coffee creamer, and finally corn syrup. Participants also observed light beams striking thin and thick plates of glass at different angles, noting the displacement of the light beam that resulted from the two refractions. The term 'normal' was introduced and the results of experiments were described in terms of bending toward or away from the normal. Finally, participants performed brief, qualitative studies of the images formed by concave and convex lenses.

In summary, this inquiry-oriented instruction engaged participants in systematic observations and sense-making, interpretive discussions of their observations. This constructivist design encouraged participants to maintain a high degree of awareness of their own thinking and understanding as they mentally processed a steady inflow of observations and made conjectures. Instruction with these characteristics has good potential to facilitate intentional learning (Bereiter & Scardamalia, 1989; Hennessey, 2003) thought to be crucial for deep conceptual understanding. The total amount of inclass instructional time devoted to the study of light was in the range of 15 to 20 hours."

Excerpted from Basista, B. & Mathews, S. (2002). Integrated science and mathematics professional development programs. ***School Science and Mathematics, 102*** **(7), 359–70.**

The Summer Institute

"During the summer of 1999, 22 middle and secondary teachers participated in the integrated science and mathematics institute. Of these 22, 10 had previously participated in an integrated science and mathematics program at WSU. The teacher participants had diverse backgrounds ranging from 2 to 35 years of teaching experience and from no professional development experience to master's degrees. Additionally, the areas in which the teachers specialized were quite different: four special education teachers, four mathematics and four science high school teachers, and 11 middle school teachers. The three districts involved were a large urban district, a suburban district, and a smaller urban and rural mixture. Student populations ranged from 75% African American students to 85% Caucasian students. These districts were chosen because they are local to the university, and WSU's preservice teachers are often placed with these districts for field experiences.

The summer institute was intensive with 72 contact hours of class over a 4-week time period, meeting 8 hours a day for 3 days a week. We immersed the teachers in inquiry-based learning environments, in which they worked on integrated science and mathematics units in cooperative groups of three or four. The general structure of the institute involved teachers spending two thirds of each day working on content units and the remainder of the day considering pedagogical issues and developing such units for use in their own classrooms.

Two different cooperative groupings were used. For the science and mathematics investigations, teachers were grouped heterogeneously with the requirements that the teachers in the group could not all teach the same grade level, or be in the same district, or teach the same subjects. For the development of units, cooperative groups were formed by same, or similar, grade-level teachers, since these teachers shared similar curricula and were often from the same district. Including both elementary and secondary science and mathematics teachers within the same groups for content investigations effectively expanded the resources and expertise available to groups in both content and pedagogical knowledge. Rich discussions resulted from these heterogeneous groups, often involving topics of vertical curriculum alignment and effective pedagogical strategies. Heterogeneous grouping typically developed mutual respect and cooperation among the different grade level and topic teachers.

To best model standards-based integrated science and mathematics teaching practices, we team-taught the institutes. In this way, teachers experienced teaching from both the science and mathematics perspectives and gained pedagogical knowledge of both disciplines. Master's degree program students who were also secondary science and mathematics teachers helped facilitate the institutes. These 'resource' teachers provided real classroom connections that aided participants in transferring the institute experiences to the precollege classroom.

Due to the diverse backgrounds, teaching assignments, and teaching environments of the teachers, the content of the institute was matched to grade 4-12 strands of the science and mathematics standards, with topics chosen for their importance and integration aspects. Content investigations started with the most fundamental concepts, usually encountered in the earlier grades, and built up to the concepts and applications of the upper grades. Even though the content was consistent with grades 4-12 standards, the teacher participants analyzed the content at an adult level in order to develop the conceptual understanding necessary to teach effectively.

We used a combination of commercial curricula and curricula we designed. Commercial resources included *Mathematical Modeling in Our World* (The Consortium for Mathematics and Its Applications, 1998a) and physics education materials (Arons, 1997; McDermott, l996). The integrated science and mathematics units we designed ourselves were adapted from preservice teacher course activities (Basista, 1998a, 1998b). When designing the units, we took great care to maintain conceptual development for both disciplines. Indeed, we chose many of the specific science and mathematics topics not only for their importance in the teachers' curricula, but also because the topics lent themselves to a high degree of integration. In every case, we made no assumptions about the backgrounds of the teachers. Each unit started with the most fundamental concepts and built teacher understanding from that basis. Since 1997, we have utilized units such as motion and graphing; shadows and proportional reasoning; and simple machines and proportional reasoning. Refer to Table 1 for the topics covered in 1999.

The integrated science and mathematics units were of a guided discovery format, with facilitator checkpoints included after conceptually connected sections. At the checkpoints, we utilized questioning techniques not only to deepen the teachers' understanding, but also to model effective questioning strategies. At these checkpoints, we often discussed pedagogical issues related to teaching the material in grades 4-1 2 classrooms. We assigned daily homework over the sections completed to help solidify the teachers' understandings of the content and to provide further examples of applications of the concepts.

The pedagogical issues addressed during the institutes related directly to the standards, their implementation, and assessment. These topics included comparisons between inquiry and traditional environments, assessing students' prior understandings, methods of modifying and/or developing inquiry-based activities, cooperative learning techniques, development of in-depth conceptual understanding, development of problem- solving skills, integration of science and mathematics, reflection on one's teaching, and authentic assessment techniques. For a sample of pedagogical content covered in the summer institute, see Table 1.

About halfway through the institute, the class was divided into groups of teachers who taught similar grade levels so that they could develop integrated science and mathematics units for use in their classrooms. At this point, the teachers began to apply the science, mathematics, and pedagogical content knowledge they had acquired during the institute to their own classrooms. During the final two days of the institute, the teachers team-taught lessons from their developed units for the class and received peer and instructor feedback.

Academic Year Support Activities

We visited the teachers' classrooms three times during the academic year to observe them, to model teaching methods, and to provide feedback about their teaching practices. During the academic year, the teachers attended three workshops, in which they shared the results of their efforts. During the workshops, pedagogical issues and district issues were frequently discussed. We encouraged teachers to maintain contact with us through phone and email.

Throughout the academic year, the teachers built portfolios documenting their efforts in modifying their teaching practices. These portfolios included lessons they had taught in their classroom, together with reflections, student feedback, and results. Teachers documented their efforts in implementing inquiry and cooperative teaching practices, developing their students' in-depth content understanding and problem-solving skills, and utilizing forms of authentic assessment."

Table 1
Summer 1999 Topics

Science Content	Mathematical Content	Pedagogical Content
Shadows	Proportional reasoning	Science and mathematics standards
Measuring heights and distances	Geometry	Inquiry
Levers	Multiple representations (graphs, diagrams, symbols)	Integration of science with mathematics
Hooke's Law	Logistics modeling	Developing problem solving skills
Population growth	Modeling vs. problem-solving	Authentic/alternative assessment
Population growth	Exponential growth	Cooperative learning
		Modifying and developing inquiry lessons
		Questioning techniques
		Reflective teaching practices
		Facilitating inquiry lessons

Excerpted from Cohen, R. & Yarden, A. (2009). Experienced junior-high-school teachers' PCK in light of a curriculum change: "the cell is to be studied longitudinally". *Research in Science Education.* 39(1), 131-155.

"A workshop that was conducted in the summer of 2005 within the framework of a teachers' course entitled 'Teaching the Cell Longitudinally' (n=12)…

The focus groups, workshop and interviews were led by the first author. The interviewed teachers were participating in long-term (3-year) professional development programmes, which were planned and conducted following publication of the new science and technology curriculum by the National Centre for Science and Technology in Junior-High School Teachers in Israel. The teachers who participated in the workshop were in-service teachers, heterogeneous in terms of age, location and teaching experience (from 2–24 years). Some of them also taught biology at high schools and one of them was a teachers' instructor-leader. Pseudonyms are used for all of the teachers mentioned in this study. The teachers' participation in the focus groups, workshop and the long-term professional development programmes as well as the interviews was completely voluntary…

The focus groups, the interviews and the workshop discussions were audio-taped, and the tapes were transcribed and analysed…

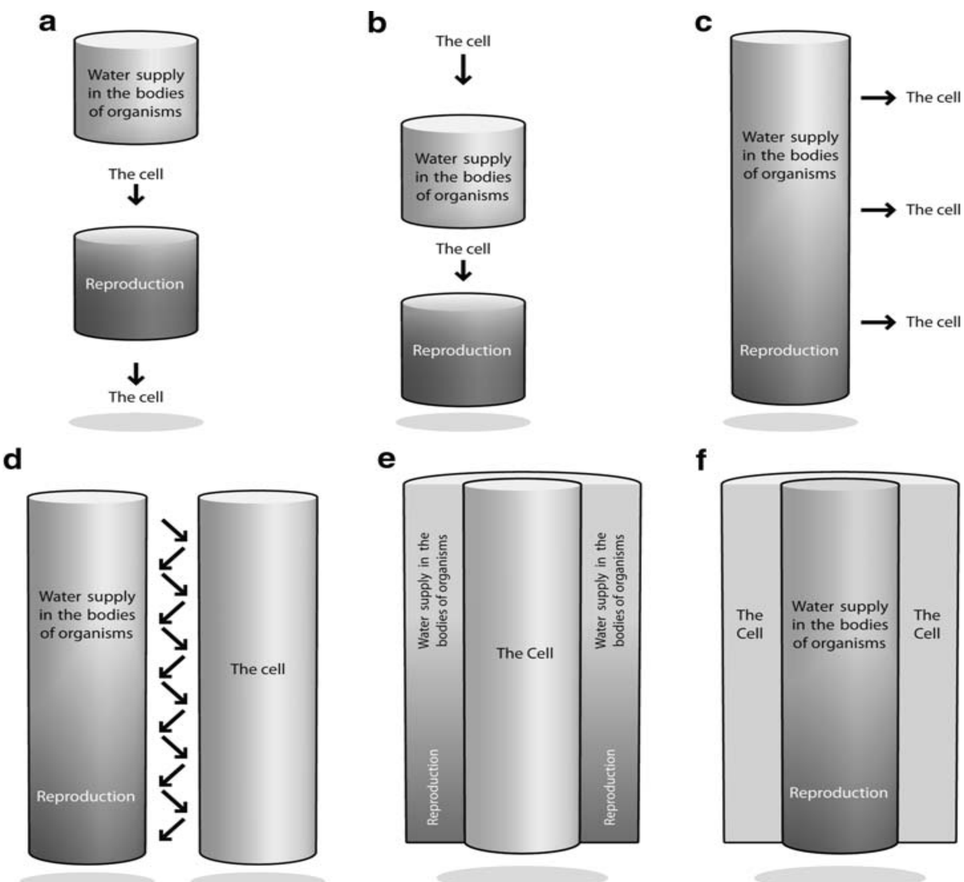

Fig. 1 Visual illustrations that may represent the curriculum guideline 'The cell topic is to be studied 'longitudinally' in conjunction with other study contents.' The study contents

demonstrated here are the topics ‘Reproduction’ and ‘Water Supply in The Bodies of Organisms’, which are studied in the 7th and 8th grades…

Questionnaire
At the beginning of the workshop, the teachers were requested to answer a questionnaire which attempted to probe their expectations of the workshop and their familiarity with learning materials for the cell topic. The questionnaire was aimed to probe teachers’ orientations towards teaching the cell topic, their knowledge and beliefs about the cell topic curriculum, students’ understanding of the cell topic and instructional strategies for the cell topic (following Magnusson et al. 1999)….

Teachers’ interpretations of the curriculum guideline When we asked the teachers who participated in the workshop to explain the meaning of the guideline – to teach the cell topic longitudinally – on a questionnaire that was handed out at the beginning of the workshop, one of the teachers said: ‘to begin teaching the cell topic in the 7th grade and continue in the 8th grade. The cell is a spiral topic’. Another teacher said: ‘to disperse the material of the cell topic throughout junior high school, referring to different issues related to the cell topic’. Some of the teachers who participated in the workshop claimed that ‘It is spiral, which means, everything I believe is needed in the 7th grade, bigger in 8th grade and even bigger in 9th grade, and I think that it should all be repeated. Every year we find out that they have forgotten what they studied during the previous year’. It seems that the teachers understood that there was a change in the teaching approach to the cell topic in junior high school, and that the topic should not be studied separately in the 9th grade, as it had been prior to the new curriculum (Israeli Ministry of Education 1988). Moreover, the new teaching method was semi-comprehensible to them. Analysis of the answers given by the interviewed teachers, those who participated the focus groups and in the workshop revealed that some of the teachers interpret the concept ‘longitudinally’ as teaching similar contents with different emphasis in each of the three years of junior high school. They reported that they repeat some aspects of the cell topic that were previously learned and keep going back to them, that they try to provide deeper and wider meanings to the cell topic prior to or during the teaching of other biological issues….

Despite the lack of information, the designers of the extensive teachers’ professional development workshops, which were offered to the teachers following publication of the curriculum, assumed that the teachers were knowledgeable with the cell topic and therefore rarely dealt with the new curriculum guideline (Kapulnik 2004). Thus, the teachers were required to change their thoughts and teaching habits, as well as their learning materials without appropriate support.”

Excerpted from Heller, J. I., Daehler, K. R., & Shinohara, M. (2003). Connecting all the pieces. *Journal of Staff Development*, 24(4), 36-41.

“The aim of the Science Cases for Teacher Learning Project is to develop teachers' pedagogical content knowledge (Shulman, 1986) - their understanding of what makes learning a science topic easy or difficult, and knowing how to present and explain the material to make it easier for learners to understand. During the 2000-01 school year, we piloted a case-based curriculum for teachers in electricity and magnetism with nearly 50 3rd-, 4th-, and 5th-grade teachers from four San Francisco Bay area districts. Teachers met monthly over the school year in six to eight sessions for a total of 20 to 50 hours. Each three-hour session began with a hands-on science investigation during which teachers actively learned science content using the same curriculum materials they use to teach students. These investigations were linked to the teaching cases. The teachers then examined and discussed cases drawn from actual lessons with events that perplexed, surprised, or disappointed the teacher in whose classroom they occurred. Project staff had helped classroom teachers write these narratives, and the lessons included student work, student-teacher dialogue, descriptions of instructional materials and activities, teacher behaviors, and the teacher's thoughts. The cases stimulated in-depth discussions among teachers in groups guided by teacher-facilitators and staff.

In the case ‘A Complete Circuit is a Complete Circle,’ for example, a 4th-grade teacher taught a sequence of lessons on complete circuits. Despite careful planning and instruction, she was baffled to find her students still didn't understand how to make a bulb light. Using the case in the professional learning session, the participants were challenged to makea bulb light up using only a battery, a wire, and a small flashlight bulb. Then they compared what worked and what didn't to develop a working definition of a complete circuit. After the science investigation, teachers worked in small groups to examine student thinking and analyze the instruction presented in the case. This led to a whole-group discussion, where teachers wrestled with the science content and explored alternative perspectives and solutions to the problem at the heart of the case. The facilitator helped focus and deepen the discussion, often asking teachers to draw diagrams and use hands-on materials or other resources to illustrate ideas.”

Evaluation framework of Science Cases for Teacher Learning Project

CRITICAL FEATURES OF SCIENCE CASE DISCUSSION METHOD	TEACHER OUTCOMES	CLASSROOM OUTCOMES	STUDENT OUTCOMES
Exploration of scientific meanings Teachers discuss, investigate, and think carefully about the meaning of specific science concepts in each case.	• Rich and accurate understanding of the science concepts in the cases. • Confidence and positive attitude toward learning, doing, and teaching science.	• Discussion and activities focus on the meaning of science concepts. • Science content meets grade-level expectations in accuracy and coverage.	• Accurate understanding of science concepts in the cases. • Grade-level appropriate knowledge of science content. • Ability to observe, look for patterns, and draw conclusions.
Focus on student thinking Teachers examine and interpret student work, talk, and behaviors in each case to determine what students understand and are thinking.	• Heightened attention to student thinking. • Understanding of what is important for students to know about the content. • Knowledge about what makes science learning difficult for students.	• Instruction and assessment elicit and build on student thinking and deal directly with what is difficult for students. • Curriculum addresses what is important for students to know about the content.	• Ability to avoid or move beyond misconceptions and errors. • Skill in thinking and communicating scientifically.
Critical analysis of practice Teachers analyze the effectiveness and coherence of instructional practices, activities, materials, and scientific representations in each case.	• Pedagogical reasoning that is analytical, complex, and detailed. • Ongoing reflection about the effectiveness of instructional practices, activities, and materials. • Skill in making science comprehensible to students.	• Instructional practices and materials communicate and develop the meaning of science concepts. • Activities are coherent, structured sequences of inquiry. • Instructional decisions are adjusted as a result of ongoing analysis of student understanding.	• In-depth understanding of science concepts. • Ability to represent scientific meanings in a variety of ways.
Experience in a learning community Teachers participate in a learning community where members engage in a process of collaborative inquiry about scientific ideas and phenomena and reflect on the teaching and learning of science.	• Ability to engage in and support collaborative inquiry. • Deliberately plans instruction that supports collaborative inquiry. • Believes that explanations and discussions are essential parts of learning science.	• Students engage in collaborative inquiry to make sense of scientific ideas. • Students interact with each other to learn science. • Students have opportunities to articulate and justify their scientific ideas and explanations.	• Skill in collaboratively making sense of science. • Ability to articulate and justify scientific ideas and explanations.

Excerpted from Henze, I., van Driel, J. H., & Verloop, N. (2008). Development of experienced science teachers' pedagogical content knowledge of models of the solar system and the universe. *International Journal of Science Education*, 30(10), 1321-1342.

"They were users of the teaching method 'ANtWoord' (in English: 'Answer'). We selected this method to be used by the participants in our study because its workbook contained many strategies emphasising the role and nature of scientific models. This book has, for instance, a chapter on 'Solar System and Universe' (Domain F), in which students have to develop models to describe and explain the earth's seasons, and discuss them in the classroom afterwards. Students also learn different models of the solar system, such as Ptolemy's geocentric model and Copernicus' heliocentric model, and debate their strengths and weaknesses (cf. Albanese, Danhoni Neves, & Vicentini, 1997)."

Excerpted from Jones, E. E. (1997). Organization, implementation, and results of an Eisenhower systemic elementary science reform project. *Proceedings of the Annual International Conference of the Association for the Education of Teachers in Science,* 1–11.

"The project includes 72 teachers and 3 administrators who attended a three-week summer workshop organized into three separate grade level groups, K-1, 2–3, and 4–5, with an average of 25 participants in each group. Each grade level workshop included 15 days of formal instruction, laboratory and field experiences. Formal instruction (generally 9:00 a.m. to 12:00) covered physical, biological, and earth science concepts appropriate for the district's new science curriculum. During laboratory time (12:30 to 3:30 p.m.), participants worked in small groups with hands-on materials and learning centers to provide them with grade level activities that supported the adopted program. Laboratory time allowed teachers to carry out individual projects and undertake long-term activities and observations that would be used in their classrooms. Project workshops supported the revised curriculum and emphasized hands-on inquiry activities, selected science content, the integration of science with other subjects, and alternative hands-on assessment. Learning by inquiry included activities emphasizing a search for solutions rather than answers revealed directly by the teacher. Particular emphasis was placed on the processes of investigations. Teachers gained an operational knowledge of integrating investigative activities with mathematics, language arts, fiction and non-fiction trade books.

Summer workshops were led by classroom teacher-leaders who worked with the same group for the entire three weeks and for the follow-up Saturday seminars. The teacher-leaders have had extensive success using investigative, hands-on approaches to science instruction and have previous experience instructing hands-on science projects for MU. They provided stability and methodology, working with teachers of their own grade level expertise. One of the professors is a botany professor providing expertise in biological science. The other is a professor of science education providing expertise in the physical sciences and science education. The two professors rotated from one grade level group to another, spending time with each as their subject matter area is scheduled.

A workshop follow-up includes inservice activities and classroom visits by the director and curriculum coordinator to assure the appropriate implementation of workshop activities and methods. Participants are observed teaching hands-on science in their classrooms, and they receive oral and written feedback. Observers offer suggestions on teaching methods, science content, materials management, learning centers, and displays. Three six-hour follow-up seminars are conducted during the 1996 fall semester by the project staff. These include instruction in science content and methodology, sharing ideas and experiences, and planning and conducting inservice activities. Workshops, seminars, inservice activities, and classroom observations are integrated for continuity.

Inservice activities enable participants to share ideas and experiences with teachers who did not participate in the project by presenting at least two inservice programs each. Possible formats include regularly assisting another teacher in the building for one full semester; grade-level inservice for building or district; and inservice for buildings other than those of the participants. The district hosted a half-day science inservice for K–5 teachers, Friday, Nov. 1, 1996. All K-5 teachers in the district and in selected Archdiocese schools were released to attend…

Each applicant's principal must confirm instructional competence and assure that the teachers are provided with the necessary hands-on materials. Selection criteria included appropriate certification, grade level, history of honors, service to district committees, and demonstrated efforts for self-improvement.

Teachers without previous experience with hands-on workshop opportunities but are eager to employ this approach in their classrooms were considered prime candidates. A special emphasis was placed on recruiting teachers from underrepresented and underserved groups and on teachers in schools with higher poverty level enrollments. Applicants from the same school who applied as a team were also given extra consideration in order to establish cooperative teams of teachers and administrators. An attempt was made to balance grade level representation."

Excerpted from Monet, J. A., & Etkina, E. (2008). Fostering self-reflection and meaningful learning: Earth science professional development for middle school science teachers. *Journal of Science Teacher Education*, 19(5), 455-475.

Focus of the Study
In this study, we investigated teacher self-reflection on learning in an inquiry-based professional development program. Participants reflected on their learning by writing structured journals, the purpose of which was formative assessment. Journal reflections provided Monet of the professional development program the opportunity to modify the curriculum and to revisit difficult concepts, depending on the specific needs of the learners. Although journal responses may not have captured everything that was learned or that remained unclear, they did help to close the feedback loop between the learner and the facilitator (Etkina and Harper 2002)….

Drawing from the research literature on best practices in professional development (Darling-Hammond and McLaughlin 1995; Loucks-Horsley et al. 1998; Loucks-Horsley et al. 2003; Sparks and Hirsh 1997), we considered the following criteria in defining the context of the Earth Science Professional Development
(ESPD) program:

• Provide opportunities for teachers to build their topic-specific pedagogical content knowledge in earth science,
• base the program on effective classroom learning and teaching practices,
• provide opportunities for teachers to collaborate with colleagues to foster a respectful and supportive learning environment,
• engage participants as adult learners using an instructional approach that teachers could model with their own students,
• support teachers to serve in leadership roles, and
• connect to and derive from teachers' work with their own students….

Program Description
The professional development program occurred over a time period of 4 months (February 2004 through May 2004). Teachers' participated in nine 2-h 15-min workshops, two 6-h Saturday workshops, and approximately 18 h of independent study (structured journals). The workshop facilitator was Monet, the first author of this manuscript. During each workshop, participants engaged in student-centered inquiry activities for approximately 1 h and 30 min, in teacher-centered activities for approximately 30 min, and group discussions for about 15 min. After each workshop, participants reflected on their learning by writing structured journals. Participants submitted their journals entries online before the start of the following workshop. Monet used the journals as a formative assessment tool. The journals helped modify the next class instruction based on the learners' needs.

The participants' learning during the workshops followed an inquiry-based approach to engage teachers in learning experiences similar to those advocated by the National Science Education Standards (NRC 1996, 2000). Teachers (in the role of students) constructed their own knowledge in ways that they could later use with their middle school students. This way they could subsequently build a deeper understanding of the content and pedagogy needed to effectively teach unit investigations 1–4 in the FOSS Earth History middle school science kit (see Table 1)….

Structured Journals
After each class meeting or field trip, teachers wrote reflective structured journals and responded to the following questions: (a) What did you learn today? (b) How did you learn it? (c) What concepts remain unclear? Questions 1 and 2 were designed to help the participants reflect on their learning. Question 3 was specifically designed to encourage teachers to think about the gaps in their own current knowledge and what questions they could ask to fill in these gaps (Etkina 2000; May and Etkina 2002).

The journal reflections became more then just a record of events; they served as a tool to aid participants in their own construction of knowledge. The process of self-reflection was a way for participants to externalize dialogue about the professional development learning experience. In addition, journal reflections provided the facilitator with an ongoing assessment of participants' learning. The facilitator read the teachers journals after each workshop. In some cases additional topics of study were added (rocks and minerals) to accommodate teachers learning needs. In other cases, discussions or investigations were prompted by the facilitator to address any questions, concerns, or difficulties that the participants had mentioned in their journals.

Excerpted from Robardey, C., Allard, D. W., & Brown, D. M. (1994). An assessment of the effectiveness of Full Option Science System training for third- through sixth-grade teachers. *Journal of Elementary Science Education, 6*(1), 17–29.

“This program provides a hands-on science approach for teachers of grades K-6. The program addresses concepts and processes in life science, physical science, earth science, and scientific reasoning and technology…

East Texas State University-Texarkana and Texarkana College were selected to co-serve as one of the field-test sites in Texas. To be a field-test site, certain requirements had to be met. First, a minimum of 10 clock hours of FOSS training had to be provided to at least 10 teachers. Second, participants had to teach and evaluate at least one FOSS lesson in their classrooms. Third, evaluation forms (provided by the Lawrence Hall of Science and completed by participants) had to be collected by the trainers and sent to the FOSS development team at the University of California at Berkeley. Fourth, it was stipulated that participating teachers should be good teachers who lack confidence in their ability to teach science.

The investigators decided that teachers, to be effective, should be trained for more than 10 hours. Therefore, training was offered as a three-semester-hour graduate (forty-five clock hours) course at East Texas State University at Texarkana. Two sections of the course were provided. One for third- and fourth-grade teachers, and the other for fifth- and sixth-grade teachers. More hours of training and control of the process were insured by employing this strategy, and it provided an added incentive for teachers to participate. This training format was employed for all FOSS sessions presented at the Texarkana site…

The investigators requested that the superintendent of each participating school district identify, in addition to good teachers who lack confidence in their ability to teach science, another teacher from the same campus who had demonstrated enthusiasm for teaching science. The investigators attempted, with this request, to establish a buddy or support structure for the teachers to increase the probability that the training would be utilized. These procedures were followed for both training courses.

The districts responded to the call for participants. As a result, 29 third- and fourth-grade teachers were enrolled in one section, and 25 fifth- and sixth-grade teachers were enrolled in the other.

An analysis of biographical data for the third- and fourth-grade teachers revealed that 14% were male, and 86% were female; 24% were 21-29 years of age, 29% were 30-39 years of age, 42% were 40-49 years of age, and 5% were more than 49 years of age; 31% had 6-15 years of teaching experience, 41% had 16-24 years of teaching experience, and 28% had more than 24 years of teaching experience; and 52% perceived science to be their primary teaching area, and 48% perceived their primary teaching area to be other than science.

An analysis of biographical data for the fifth- and sixth-grade teachers revealed that 16% were male and 84% were female; 22% were 21-29 years of age, 39% were 30-39 years of age, 39% were 40-49 years of age, and 0% were more than 49 years of age; 24% had 0-5 years teaching experience, 52% had 6-15 years of teaching experience, 24% had 16-24 years of teaching experience, and 0% had more than 24 years of teaching experience; and 96% perceived science to be their primary teaching area, and 4% perceived their primary teaching area to be other than science.

The designation of East Texas State University-Texarkana and Texarkana College as a leadership site in a FOSS center entitled the two institutions to receive one complete set of FOSS materials packaged in the form of modules for use in providing training. Each module is divided into two parts, printed materials and an equipment kit designed for use by a maximum of 32 students.

Each participating school district received one complete set of the printed FOSS curriculum materials, a handbook containing appropriate science background information, and instructions for teaching lessons. The school districts made these printed materials available to the participating teachers. However, FOSS equipment kits, which contain hands-on science materials, were not provided to the participating school districts or teachers…

To insure maximum participation of teachers, the best time of the day and week to hold classes was determined from input provided by the prospective participants. Both classes were taught in early afternoon after the public schools were dismissed. Each class met three hours per week for 16 weeks, providing a total of 48 clock hours of training and assessment.
In addition to participating in the FOSS training, teachers in both classes had to meet the following requirements:

(1) Each teacher had to demonstrate, in class, his or her understanding of the FOSS concepts by teaching fellow class members a lesson from one of the modules.
(2) Each teacher had to teach a lesson from one of the modules to students in his or her class at school."

Excerpted from Shen, J., Gibbons, P. C., Wiegers, J. F., & McMahon, A. P. (2007). Using research based assessment tools in professional development in current electricity. *Journal of Science Teacher Education*, 18(3), 431-459.

The Background of the Class

"The sample of this study consists of subjects who enrolled in a course for K-8 science teachers about electricity and magnetism in the fall, 2003. This is one of twelve courses offered in the science outreach program at Washington University. The courses are part of a continuing education certificate program in elementary science education and of a more extensive program leading to a master's degree in elementary science education. The teaching team for the course consisted of two instructors, the second author (professor of physics) and the third author (science educator); two teaching assistants (one kindergarten teacher and one elementary teacher who had taken this course); and another assistant whose main responsibility was making and analyzing the assessment, the first author (physics graduate student).

The course aimed to prepare teachers to conduct inquiry-learning which focused on hands-on activities and observations and constructing scientific models, and also to bring inquiry-learning environment back to their classrooms. The instructors carefully selected hands-on activities, aligned modules with the National Science Education Standards (National Research Council, 1996) and Missouri Show-Me Standards (Missouri Department of Elementary and Secondary Education, 2005), and emphasized the storyline of the physics content (Shen, Gibbons, Wiegers, & McMahon, 2005). The course used the following curriculum modules: Batteries and Bulbs (Elementary Science Study, 1986), Magnets (Delta Science Module, 1996), STC's Electric Circuits (National Science Resources Center, Science and Technology for Children, 1991a), and STC's Magnets and Motors (National Science Resources Center, Science and Technology for Children, 1991b).

In the course, the teachers performed hands-on activities, usually in small groups, reflected on the phenomena observed, and discussed with classmates and instructors. From the reflection the teachers and course instructors constructed a list of observations as shown below:

1. The curly wire, the filament, is thicker in the fat-filament bulb (a number 41 bulb) than in the thin-filament bulb (a number 48 bulb).
2. A metal path from the + terminal of the battery to one side of the bulb, through the curly filament to the other side of the bulb, and on to the - terminal of the battery will result in the bulb lighting.
3. The fat-filament bulb is brighter than the thin-filament bulb when connecting to a battery.
4. Wood, plastic, paper, or cardboard do not complete an electrical path.
5. Metal or salt water (a lot of salt) will complete a path.
6. A bulb is brighter with two batteries connected with terminals + to - (in series). A bulb is not brighter with two batteries connected + to + and - to - (in parallel).
7. Nichrome wire in series with a bulb dims the bulb's glow. The longer the Nichrome wire, the dimmer the bulb. Using equal lengths of Nichrome wire, the bulb is dimmer with the thinner wire.
8. In all of these observations, the position of the bulb in the circuit does not make a difference.
9. The connecting wires that complete a circuit do not glow like the filament in the bulb.

10. The fat-filament bulb is dark and the thin-filament bulb lights if they are connected in series.
11. A bulb in series with a diode lights if the arrow on the diode points toward the negative terminal of the battery. If either the diode or the battery is reversed, the bulb does not light. With the diode in the circuit, the bulb is not as bright as without the diode. Again, two batteries in series can make the bulb brighter with the diode in the circuit.
12. With a diode in the circuit, the relative orientation of the diode and the battery matters, but not that of the bulb. Bulbs look directional because of the shapes of their bases, but by behavior and on dissection they are not.
13. After lighting a bulb for a long time, a battery wears out; moved to a new circuit, it also fails to light the new bulb. The bulb usually does not wear out; moved to a new circuit with a fresh battery, the bulb lights as before.

The teachers were asked to describe explicitly their mental models of currents. Then they were asked to identify the observations that were not consistent with their mental models. This strategy worked well for teachers, helping them to accomplish conceptual change towards the accepted scientific notions (Gibbons et al., 2003). There were 18 teachers enrolled in the course initially, but three dropped later. About three quarters of the teachers majored in education, and only two teachers majored in science, engineering or architecture. One teacher was in her twenties, three teachers were in their thirties, six teachers were in their forties and four teachers were in their fifties or older. There were two males in the class.[1] The class met every Tuesday evening from 4:30 p.m. to 7:00 p.m. for 15 class periods. Each teacher was required to submit a journal entry every week, and to conduct and report on a final teaching project on the topics that were taught in the course."

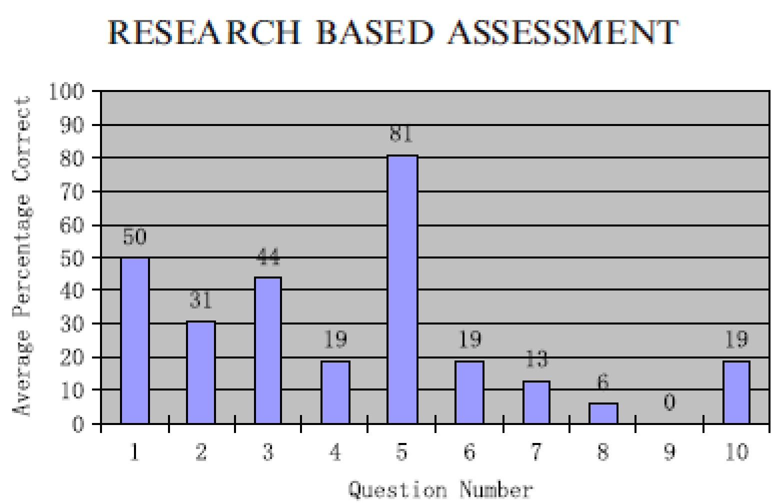

Figure 2. *Correctness of each question of EMKS1.*

[1] The background data are from the 16 teachers (2 dropped later) who took the pre-test survey.

Excerpted from van Driel, J. H., Verloop, N., & de Vos, W. (1998). Developing science teachers' pedagogical content knowledge. ***Journal of Research in Science Teaching, 35*****(6), 673–695.**

"The present study was conducted within a long-term research project in The Netherlands on chemical education, in which the concept of chemical reaction was central (De Vos & Ver-donk, 1985) The concept of chemical equilibrium was chosen because the introduction of this concept challenges the conceptions about chemical reactions students have derived from previous education. Therefore, the introduction of chemical equilibrium offers an opportunity to study processes of conceptual change with respect to chemical reaction among students. A specific re-search purpose concerned the identification of factors either promoting or hindering such processes. Research results focusing on student learning are described by Van Driel, De Vos, & Verloop (in press).

To achieve this purpose, both (a) an experimental course on chemical equilibrium for students of upper-secondary education, and (b) an in-service workshop for chemistry teachers using the experimental course in their own classes were designed…

The workshop's overall purpose was to enhance chemistry teachers' PCK of chemical equilibrium. Specifically, the aims were to improve chemistry teachers' abilities to recognize specific preconceptions and conceptual difficulties related to chemical equilibrium, and to promote their use of interventions and strategies promoting conceptual change during classroom practice. These goals were to be realized by a combination of teachers' use of our experimental course in their own classes and their participation in the workshop. Therefore, workshop meetings were organized before, during, and after the period in which the experimental course was used.

As most of the workshop's participants were chemistry teachers who had been teaching chemical equilibrium for several years, we expected all of them already to possess PCK about this topic to some degree. On the other hand, we assumed that these teachers could benefit from the results of research on student learning of chemical equilibrium and of our educational analyses of chemical literature and curriculum materials dealing with chemical equilibrium. Combining these assumptions, we designed the workshop meetings as follows:

1. The first meeting focused on the PCK of chemical equilibrium participants held on entering the workshop. Therefore, participants performed and discussed chemical experiments and assignments from current chemistry textbooks. Moreover, they were asked to react to authentic student responses. For this purpose, research results with respect to student learning of chemical equilibrium were used as input in the workshop. (A similar design was applied by Shymansky, Woodworth, Norman, Dunkhase, Matthews, & Liu, 1993.)
2. The following two or three meetings coincided with the implementation of the experimental course. These meetings were used both to discuss recent practical experiences as well as to prepare participants for topics following shortly after the meeting, in the way described above.
3. A final meeting was organized to reflect on experiences with the experimental course. In this meeting, teachers not only exchanged and discussed their personal experiences, but were also presented with specific results of our research. The latter was meant to facilitate reflection on a theoretical level. Also, this meeting served to evaluate the experimental course. Therefore, participants were asked to fill in an evaluative questionnaire.

As one can see, the workshop was not designed to provide participants with checklists or recipes for the effective teaching of chemical equilibrium. Instead, adopting constructivist views, we tried to support and facilitate participants' construction of PCK by providing them with both practical experiences and results of research, and by organizing interactions between these two possible sources of knowledge construction.

The experimental course aimed at fostering conceptual change among students by (a) including assignments designed to challenge students' existing conceptions, and (b) stimulating active student engagement through small-group discussions and the execution of chemical experiments by students. This course design was based upon the assumption that for conceptions to be changed, dissatisfaction with existing conceptions is a prerequisite (Posner, Strike, Hew-son, & Gertzog, 1982). Through small-group discussions facilitated by questions in the course material, students should try to explain phenomena conflicting with their initially held conceptions. Together, they should be able to solve the anomalies and reconstruct their conceptions. Obviously, the teacher has a crucial role in this design in helping students to overcome preconceptions and in guiding them toward conceptions that are chemically more valid.

From the teachers' perspective, this design also aims at developing their PCK. As teachers spend most of their time in classroom listening to and participating in student discussions, they are presented with opportunities to gain understanding of student reasoning, of their preconceptions and possible misconceptions, and of factors either promoting or hindering conceptual change. While taking part in student discussions, teachers can explore ways of explaining or representing subject matter. Reacting to student responses, they can expand their repertoire of approaches that may be effective for certain students in specific situations.

Applying a grounded theory approach (Strauss, 1987), our research project consisted of three consecutive research cycles. In this article, we focus on the in-service workshop that was part of the third and last cycle of our research. The workshop sessions were attended by 12 participants. All of them had an academic background in chemistry and more than 5 years of experience in teaching chemistry in upper-secondary education. As the topic of chemical equilibrium is a key subject in the national curriculum, all participants were familiar with this topic, both as a learner and as a teacher. All participants had chosen to attend to the workshop on a voluntary basis. Mostly, their choice was inspired either by interest in the topic or by the wish to innovate their educational practice. Most of the participants had previously taken part in similar workshops, for example, on the chemical reaction, electrochemistry, stoichiometric calculations, and the like. Some of them had previously been subjected voluntarily to research describing this as 'an instructive experience.'"

Excerpted from Williamson, V. M., & Jose, T. J. (2008). The effects of a two-year molecular visualization experience on teachers' attitudes, content knowledge, and spatial ability. *Journal of Chemical Education*, 85(5), 718-723.

The Workshops

“The molecular visualization workshop consisted of two, three-week sessions held over two consecutive summers. This workshop was offered in conjunction with the Information Technology in Science (ITS) Center for Teaching and Learning at Texas A&M University, which was designed to enrich and diversify national standards-based instruction in K–12, undergraduate, and graduate education in science. The molecular visualization workshop met for three weeks each summer in half-day sessions (four hours) Monday through Friday.

During the first summer session, the goals were to:

- Introduce participants to molecular visualization materials available for education and research purposes (and available for free or at low cost)
- Investigate literature on student misconceptions of the PNM; state and national standards; and the effects of molecular visualization on student understanding
- Identify critical attributes of molecular visualization needed to enhance learning in light of the investigation of the chemical education research literature
- Allow participants to critique educational molecular visualization materials
- Produce and practice a professional development presentation to inform other teachers about one or more of the visualizations that could be used in the classroom
- Infuse molecular visualizations into participants’ classrooms (This was a goal, although Williamson et al. *[26]* discusses the differences between the intended versus actual use and the identified barriers to the use of molecular visualizations in the classroom.)

The products of the first summer session included professional development materials to use in a presentation to other teachers. These materials included a presenter’s guide, handouts, and so forth, needed for the audience.

During the following academic year, workshop participants were to deliver their professional development session to at least five other teachers, gather feedback about the session, edit the materials, and submit the final versions of the presenter’s guide and audience materials. Participants were asked to journal their use of molecular visualizations and record their experiences during the academic year. We expected that participants would use molecular visualizations in the classroom and would also help other instructors to use them as well.

During the second summer session, the goals were to:

- Move participants toward more expert use of a few molecular visualization materials available for education and research purposes (and available for free or at low cost)
- Continue to investigate the literature concerning: (a) student misconceptions of the PNM; (b) state and national standards; and (c) the effects of molecular visualization on student understanding
- Continue to critique educational molecular visualization materials

- Produce and practice-teach a learning cycle incorporating a molecular visualization in one or more of the phases

The products of the second summer session included a student and teacher version of a learning cycle. A learning cycle is an instructional strategy derived from constructivist learning theory, consistent with the nature of science, and has three sequential phases *(27).* The titles of these phases have changed with various curricula; nonetheless, the basics include:

1. Exploring and gathering data: students are actively involved in experimentation and gathering data on variables
2. Discussion and concept invention: the concept invention phase is an inductive activity involving logical organization, comparison, and interpretation of data, resulting in a generalization about the variables
3. Expansion and application: students are asked to apply the generalization in a new situation or examine another aspect of the concept

Molecular Visualization Materials Used

A number of types of molecular visualizations were used. These included programs to view and rotate molecules, those to draw molecules, and those to construct animations. We also used animations produced by others that could be accessed via videotape, CD-ROMs, and the Internet. Because educators do not typically have access to costly computer programs, we made sure that only low-cost or no-cost programs and materials were used. See List 1 for the visualizations used in the workshop….

List 1. Visualization Resources Used in the Workshop

Types or Sources	Resources
Software to view and rotate multidimensional objects	Rasmol *(28)* Chime *(29)*
Software to draw molecules	ISIS Draw *(30)*
Videotape animations	ChemistryAnimation Project *(31)*
CD-ROM animations	Chemistry Animations CD *(32)* ChemFile Interactive Tutor *(33)* Publisher CDs
Software to create animations	ChemSense *(34)*
Internet	Web sites offering visualizations

The differences seen following the first summer session speak to the *intensive* nature of the experience for some, if not all the participants. When participants were asked on the end-of-summer survey what their least favorite feature of the workshop was, one teacher responded:

> Just keeping things sorted out mentally was difficult for me. I felt that I was not able to keep up the pace of learning so many new functions and so much information everyday. Now that I have been home and sorted through some of my stacks some of it is less blurry than I thought it would be but I know I will have many questions and need much help to finish the list of things to do now that we are home.

This sentiment may explain why participants were less interested in working with an experimental curriculum. Conversely, while in the protected environment of the workshop, participants seemed to take comfort in the fact that they were working with one another and encouraging one another to do well. (Participants more strongly agreed that working with others helped them learn the material and responded more positively that others pressured them to do well.) One participant responded with the following statement in the directed writing:

> I learned so much that I can use in my classroom. Much of what I am talking about I learned during group discussions, even over lunch or dinner."