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Supporting Science Teacher Learning: The Role of Educative Curriculum Materials

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Introduction

Science education is the focus of many reform efforts. Specifically, reformers are suggesting teachers utilized inquiry based, student centered instructional practices that will facilitate students' construction of knowledge. Embedded technology use to support students in a deeper understanding of fewer topics is encouraged. In addition, reforms based on these recommendations are being attempted on a large scale. Many states and school districts have made science education a part of their overall effort to improve instruction for students in their schools. However, reform-based curriculum designed to support students' construction of knowledge in science through inquiry relies on teachers to fulfill this vision for our students. For many teachers this will mean substantial changes in instructional practices. Since what teachers do in their classrooms depends largely on their knowledge, teachers will need to learn a great deal to be able to enact reform-based curriculum (Borko & Putnam, 1996; Wallace & Louden, 1998). Teachers, like other learners, will need supports. Educative curriculum materials, curriculum materials designed to address teacher learning as well as student learning, is one potential vehicle to support teacher learning on a large scale (Ball & Cohen, 1996). Our work is embedded in an ongoing urban systemic initiative of a large public school district to reform science and mathematics education. As part of this effort, science curriculum materials were developed that were consistent with social constructivist ideas, addressed national and local goals for student learning and educative for teachers.

Theoretical Framework

An approach to science instruction that addresses the concerns of reformers is project-based science (Krajcik, Czerniak, & Berger, 1999; Ruopp, 1993a; Tinker, 1996b). Project-based science involves students in extended inquiry as they investigate answers to a driving question (Krajcik, Czerniak et al., 1999; Tinker, 1996b). Integrated uses of technology along with collaboration among learners are

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important components that support students in developing understanding of science, which they demonstrate through development of artifacts (Ruopp, 1993b; Tinker, 1996a).

The assumptions that provide the foundation for project-based science are derived from a social constructivist perspective (Blumenfeld, Marx, Patrick, & Krajcik, 1996; Krajcik, Czerniak et al., 1999). It is assumed that students need to find solutions to real problems by asking and refining questions, designing and conducting investigations, gathering and analyzing information and data, making interpretations, drawing conclusions, and reporting findings. Collaboration and conversation is also considered essential. Collaboration involves students building shared understandings of ideas and of the nature of the discipline as they engage in discourse with their classmates and adults outside the classroom (Krajcik, Blumenfeld, Marx, & Soloway, 1999).

Our research group has developed curriculum materials based on the premises of project-based science. Our curriculum design is based on principles that are consistent with what is known about teaching and learning (Singer, Marx, Krajcik, & Clay-Chambers, 2000). These include: alignment with standards, contextualization, sustained student inquiry, embedded learning technologies, collaboration, assessment techniques, and educative materials for teachers. Curriculum materials created by using these design principles can promote deep understanding of science concepts and inquiry strategies and address the needs of diverse students (Krajcik, Blumenfeld et al., 1999).

Enacting reform-based curriculum is not easy. Specifically we know that project-based science curriculum presents several challenges to teachers. Common challenges faced by teachers have been found in several schools with teachers enacting project-based science (Marx, Blumenfeld, Krajcik, & Soloway, 1997; Scott, 1994). Challenges included teachers' knowledge of: inquiry versus a more linear flow of information, various techniques to promote learning such as coaching or modeling, specific instructional strategies such as prediction-observation-explanation, management of the classroom, science understanding of non-trivial content, new technologies to represent content and support inquiry, and non-traditional assessment. Teachers' ability to enact reform-based curriculum such as ours depends on their learning new instructional practices.

One way to support teacher learning is through curriculum materials designed to be educative for teachers (Ball & Cohen, 1996). Curriculum materials including textbooks, teacher guides and technology-based materials, whether supplied by publishers or researchers, have traditionally been designed with student learning as the goal. However, materials can be designed to support learning by teachers as well as by students. Educative curriculum materials are designed to support teacher learning, as teachers use the materials to support student learning. Educative curriculum materials cannot replace other professional development opportunities but they do have a unique role. Unlike summer workshops or peer collaboration, teachers will be able to use curriculum materials over an extended period of time in the context of their classroom. Teachers are also accustomed to using such materials to plan and structure student activities (Ball & Cohen, 1996). Teachers' use of educative curriculum materials in the classroom with their students may help to situate teacher learning (Borko & Putnam, 1996; Brown, Collins, & Duguid, 1989). In addition, because nearly all teachers use curriculum materials in nearly all schools, these materials can be used to address reform issues on a large scale.

Designing Educative Materials

Although many reform-based curricula are being developed, they have not been explicitly designed to support teachers' learning. It is not enough, however, to give teachers directions on how to enact curriculum (Franke, Carpenter, Levi, & Fennema, 1998; White & Frederiksen, 1998). Ball and Cohen suggest curriculum materials can be educative for teachers by offering support for teachers in thinking about: (a) content beyond the level suggested for students, (b) underlying pedagogy, (c) developing content and community across time, (d) students, and (e) the broader community.

We are asking teachers to use new ways to represent content and new strategies to support student construction of knowledge, both of which bring to light students' thinking in ways not possible in traditional instruction. Thus, during reform teachers become novices again making a transition from novice to expert necessary (Tschannen-Moran, Hoy, & Hoy, 1998). Expert-novice studies highlight the importance of specialized and domain specific knowledge (Carter, 1990). Expert teachers have a rich, interwoven and accessible knowledge of classroom practices (Borko, Bellamy, & Sanders, 1992; Borko & Livingston, 1989). Expert science teachers know many more representations and use a greater variety of instructional strategies (Borko et al., 1992; Clermont, Borko, & Krajcik, 1994). Knowledge of students' thinking is critical to allowing science teachers to respond to students during class (Borko et al., 1992). Novice teachers' knowledge in these areas on the other hand is nearly non-existent (Borko et al., 1992; Borko & Livingston, 1989; Clermont et al., 1994).

For reform in science to be successful, experienced classroom teachers will need to learn new classroom practices. A framework of knowledge areas necessary for exemplary practices has been proposed (Shulman, 1987). Shulman includes three main knowledge types: content, pedagogical, and pedagogical content knowledge (PCK). Content knowledge is the subject matter to be taught, in our case science. Pedagogical knowledge includes the "broad principles and strategies of classroom management and organization that appear to transcend subject matter" (Shulman, 1987 p. 8). Pedagogical content knowledge is an amalgamation of content and pedagogy in a specific context (Gess-Newsome, 1999). For science teachers PCK includes knowledge of science specific strategies, various ways to represent content and students' thinking about science ideas (Magnusson, Krajcik, & Borko, 1999). Because our curriculum materials are intended to be used by teachers as they plan lessons for their students, teachers will need to access knowledge of content and pedagogy as they think about their students in a particular context.

Shulman (1986) also suggests that teachers can learn the knowledge needed during practice through stories or cases. Cases are rich descriptions of classroom events that illustrate theory. Teachers themselves use stories, also called episodes or narratives, to describe their knowledge and base their stories on their own experiences in the classroom with their own students (Brown et al., 1989; Guskey, 1986; Pajares, 1992). Teachers in general strongly believe that they learn by doing (Borko & Mayfield, 1995; Fenstermacher, 1994; Richardson, 1990). Although curriculum materials are not illustrative stories describing real events, annotated curriculum such as ours does bring together ideas about content, pedagogy and PCK in one specific lesson to support teacher learning.

It is also recommended that teachers' learning be situated in the classroom (Borko & Putnam, 1996; Brown et al., 1989). Educative curriculum materials are situated in the context of the classroom and will be used by teachers to plan instruction for their students. Our materials include features intended to be educative for teachers that surround and are embedded within the instructional events designed for students.

Keeping in mind Ball and Cohen's suggestions for educative curriculum as well as known challenges to inquiry-based curriculum (Marx et al., 1997), we included features intended to be educative for teachers within our curriculum materials. The educative features also incorporate five design principles consistent with what is known about teacher learning. These include: (a) addressing each area of knowledge necessary for exemplary practices — content knowledge, pedagogical knowledge, and PCK, (b) situating teacher learning by meshing the content of the support to lessons for students, (c) linking different knowledge areas within lessons, (d) making knowledge accessible to teachers by included short scenarios in the language of teachers or students involved in the lesson to illustrate or model the intended practice when possible, and (e) addressing immediate needs for understanding as teachers plan lessons that will be enacted within a short time.

Educative features in our materials included science content explanations for the teacher beyond the level of understanding suggested for students, overviews of the entire unit and portions we called learning sets to explain the reasoning behind the sequence and flow of the lessons, short scenarios to illustrate how an idea or activity may be introduced in connection to other ideas, support for using artifacts as assessment tools at the beginning and end of lessons, and notes to the teacher embedded within lessons. The embedded notes address the specific strategy and how it supports student thinking, the representation and how it presents science content to students, and student ideas involved in the lesson such as probable prior knowledge or experience, responses and demonstration of understanding, and appropriate level of understanding and concepts that are challenging for students.

Creating materials with teacher learning in mind is a new idea and is yet to be well developed or researched. Although other materials may include features that are educative for teachers, currently only two curriculum projects claim that they have developed educative curriculum materials. One of these projects is the focus of this study. The other is a mathematics curriculum for elementary students designed by TERC (1995). One of the goals for their elementary mathematics materials, *Investigations in Numbers, Data and Space*, is to communicate mathematics content and pedagogy to teachers. Research using TERC's materials showed educative materials to be a promising vehicle to contribute to teacher learning (Collopy, 1999). Collopy's study however followed only two teachers as they used TERC's materials with their 5th grade students. One teacher used the materials and changed her practice to include more constructivist ideas. The other teacher however discontinued using them and after an initial attempt at new practices reverted to more traditional methods. Educative curriculum material is an intriguing idea that is yet to be well defined or implemented. Our research contributes to our knowledge of how and in what areas these materials could be helpful to teachers.

Our Questions

Although we do know that teachers need to learn new methods and content to enact reform-based curriculum, we do not know what role educative curriculum materials might play in supporting their learning new practices in the classroom over time or how such materials should be designed. We have proposed design considerations based on research in teacher knowledge and learning and have developed materials based on this model. To continue our work in developing materials for teachers we need to find out how the use of educative curriculum material influences teachers' practices. We were guided by three sub questions: (a) how do teachers use educative curriculum materials, (b) what do teachers understand when they use educative curriculum materials, and (c) what are teachers' classroom practices like when they use educative curriculum materials? Each of these questions plays a role in answering the main question of this study. What is the role of educative curriculum material in supporting reform-based practices in science education?

Educative curriculum features were included in the curriculum materials given to teachers. We attempted to design curriculum materials that were not teacher proof (Apple & Jungck, 1990), but would guide teachers in experiences that would enable them to construct knowledge about teaching and that would enable them to implement reform-based instructional practices. Also, we encouraged teachers to modify curriculum to meet the needs of their students and circumstances. Educative features that address areas that have challenged teachers new to this type of curriculum in the past (Marx et al., 1997) and recommended by Ball and Cohen (1996) were included in these materials. Our science materials included information to explain content and pedagogy, as well as specific information about strategies, representations, and students' ideas (PCK) embedded within lessons. We utilized Shulman's conceptualization of three main areas of teacher knowledge to examine teachers' use of and learning from the curriculum materials. The potential of educative curriculum materials to support teacher learning will be illustrated by the description of how teachers' practice is influenced by the use of our educative curriculum materials.

Methods

Our research design combined teacher interviews and classroom observations over time. By observing teachers' practice in the classroom and interviewing teachers about their plans and reasons for the lessons we gained information about what teachers understand from educative materials. Likewise, data on the influence of educative materials and their use by teachers were collected both through observation and teacher interviews. We examined teachers' use of educative features in the materials and their classroom practices across a 10-week unit on force and motion. Using the intended curriculum as a guide, we looked for connections between use of materials, support by educative features in the materials and teacher practices in the areas of content, pedagogical, and pedagogical content knowledge.

Background

This study was embedded in a National Science Foundation funded urban systemic initiative to reform science and mathematics instruction. Project-based science curriculum materials for a unit on force and motion were developed as part of the larger study (Blumenfeld, Fishman, Krajcik, Marx, & Soloway, 2000; Singer et al., 2000). Teachers participating in this reform effort were supported by a two-week summer institute, three Saturday sessions and weekly in-classroom support offered by both university and school personal (Fishman, Best, Foster, & Marx, 2000). The educative curriculum features of the materials were only one part of the professional development involved in this reform effort. This study was conducted in three urban middle schools located in low SES neighborhoods selected to participate in initial stages of the reform effort (Krajcik, Marx, Blumenfeld, Soloway, & Fishman, 2000). Students in these schools were over 95% African-American and scores on statewide standardized testing in science were reported as below grade level.

The curriculum materials used in this study were developed to involve 8th grade students in a 10-week extended inquiry. They investigated the driving question, "Why do I need to wear a bike helmet?" (Schneider & Center for Highly Interactive Computing in Education, 1999). Use of motion sensors with computer interface was integrated along with collaboration among learners to allow students to develop understanding of Newton's 1st law, velocity, acceleration and force. Students developed various artifacts to both develop and demonstrate their understanding. Teachers were introduced to these materials during the two-week summer institute.

Teacher participants had a wide range of teaching experience and content backgrounds (see Table 1), but all taught eighth grade in schools selected to participate the larger reform effort. All three were female and African-American. Teachers enacted the force and motion curriculum for the first time during the fall term of 1998 in several of their classes. Sections were chosen for observation based on compatibility with times staff could be in schools to collect data and provide support. Although they were not selected as a statistically random sample, their disparate backgrounds made this group representative of middle school science teachers across the district. For each, this was their initial experience with the reform effort and our curriculum materials. Prior to the project, teachers had limited experience with project-based science, physics and the use of technological tools to support inquiry.

Table 1
Background and Experience of Teachers Participating in this Study

Teacher	Ms. Franklin	Ms. Cole	Ms. Turner
Preparation	B.A. in education - elementary science & social studies M.A. in education - elementary mathematics	B.A. in education - elementary science	B.A. in secondary education - biology & physical education M.A. in educational administration
Certification	All subjects grades k-8	All subjects grades k-8	Science grades 7-12
Teaching Experience	16 years middle school science	1 year middle school science	4 years middle school science

Educative Features of the Materials

The curriculum materials included teacher materials and student worksheets. In the teacher's material the unit was divided into 5 sections called learning sets, based on main ideas. Each learning set consisted of several one to three day lessons. Teachers' materials included educative features for teachers in the areas of content, pedagogy and pedagogical content knowledge (see Tables 2, 3 and 4).

The materials offered teachers content support before each learning set of the unit to help them understand Newton's 1st law, velocity, acceleration and force beyond what was suggested for student understanding. For example content support for teachers included the idea that standing still could also be thought of as a constant velocity with a value of zero thus combining constant motion and standing still in one definition of acceleration. Lessons for students listed constant velocity and zero velocity each time the idea of acceleration was addressed.

Pedagogical support included help in understanding the sequence and flow of the lessons and assessment through artifacts. Descriptions of the unit and each lesson were given before lessons to explain how and why lessons were sequenced to connect and develop both ideas and skills. For example teachers were supported in understanding that the concept of force was addressed early in the unit to help students think about Newton's 1st law but force would also be addressed again later in the unit to link ideas of mass and changing velocity. Explanations of how students would use ideas to develop artifacts, which could be assessed for understanding, were offered both before and after lessons. For example a suggestion that students' explanation of their computer generated graphs could be evaluated to determine students' readiness for the next lesson was included at the end of the first lesson using motion sensors.

Table 2

Description and Examples of Educative Features for Content Knowledge

Content knowledge topics in this curriculum: force, Newton's 1st law, velocity, acceleration, variables, and motion graphs

Educative Features	Examples
Science Understanding for the Teacher: Explanation of science content to a level beyond that suggested for students, included at the beginning of each learning set.	When an object is moving such as a student on a bike or an egg on a cart, it is changing distance per time in a certain direction. This means that at each consecutive time interval the object is at a different location. The rate of changing distance per time in a direction is the object's velocity. Velocity is the change in position over change in time. Speed is a component of velocity. Speed is the change in distance over time. Velocity can be positive (forward) or negative (backward). The positive or negative indicates direction. Speed is always positive number because it measures how much motion but not the direction.

Table 3

Description and Examples of Educative Features for Pedagogical Knowledge

Pedagogical knowledge topics in this curriculum: sequence and flow of lessons, and artifacts as assessment tools

Types of Educative Features	Examples from Materials
Overviews describing how concepts are linked and developed through lessons and across the unit. Overviews of entire unit	Students participate in several investigations while exploring each stage of the driving question. Students begin by examining the design of an investigation and gradually develop the ability to design their own investigations. They first focus on experimental variables as they explore the relationship between mass and Newton's first law. As students continue their exploration of motion, motion sensors are used to create computer-generated graphs. Students develop understanding of velocity, acceleration, as well as how to read and interpret motion graphs. Next the investigation of gravity and mass focuses on collecting and interpreting data again with the use of motion sensors to determine changing velocity. When students investigate the relationships between force, mass and acceleration they select independent, dependent, and control variables and focus on conclusions. Students will use motion sensors again in their own investigation of their egg helmets.
Overviews of learning sets	Learning Set One illustrates for students what can happen without the protection of a helmet. Students first hear one boy's personal experience with critical injury in the video Jell-O in a Jar and share their own experiences with bicycle riding and perhaps accidents. Students are then given a common experience when they watch an egg ride a cart down a ramp without a helmet. This event will guide students' inquiry through out this project as they explore what happens in a collision.

Table 3 Continued
Description and Examples of Educative Features for Pedagogical Knowledge

Types of Educative Features	Examples from Materials
Overviews of lessons	Students then observe the egg and cart demonstration again and use the concept of Newton's 1st law, force, velocity, and acceleration to explain the process of the egg getting pitched off the cart and getting into an accident. This discussion raises the question "When I get pitched off my bike, why do I get hurt?" This question becomes the focus question for the next part of the inquiry.
Short scenarios in the voice of the teacher or student to illustrate how an idea or activity may be introduced in connection to other ideas.	Over the last couple of sessions we have observed a number of demonstrations and have done a few experiments to help us answer, "How fast was I going when I got pitched off my bike?" You have just brainstormed a list of ideas and concepts that you have learned. Now you will continue to construct the concept map that you began in learning set one to show how all the ideas or concepts you learned are related. As before, you will first work independently to make a list of statements that relate one concept to another. Then you will actually construct your map.
Artifact assessment explanations at the beginning of lessons.	*After an initial explanation of a collision.* Students' stories about motion and their explanations can be assessed to determine their initial understanding of motion and collisions. This will help both you and the students to observe their progress in developing understanding during this project.
Artifact assessment explanation at the end of lessons	*After a graphing activity.* Look at the graphs that students have created today. You can assess their ability to use the motion sensors as directed. This is an important skill, as students will be using these sensors repeatedly in this and the following learning sets. Make sure everyone can pick up their motion with the sensors, are not starting or ending too close to the sensor or moving to the side resulting in graphs that jump around or "flat line" indicating that the student was not in front of the sensor. Also check that they can resize the graph and read the numbers for position or time from their graph. This will mean they are ready to go on the next activity. You will not need to read every prediction and explanation but do check these things. You will also know which students will need more assistance in the next activity.

Educative features to address pedagogical content knowledge (PCK) were embedded within each lesson. These supports targeted: (a) how to use the specific strategy, how it develops science content ideas, and how it supports student thinking; (b) how to use the specific representation, how it represents science content ideas, and how it supports student thinking; and (c) student ideas involved including probable prior knowledge and experiences, probable responses and demonstration of understanding, and appropriate level of student understanding and challenging concepts. For example, a note to the teacher explained the importance of students observing the computer screen while walking in front of a motion sensor, as this would help the student to link their motion to the resulting graph.

Table 4
Description and Examples of Educative Features for Pedagogical Content Knowledge

Pedagogical content knowledge (PCK) topics in this curriculum: science specific strategies, representation of science concepts, and student thinking

Types of Educative Features	Examples from Materials
Science Specific Strategies How to use strategy	*For a graphing activity using motion sensors.* Make sure that student refer to their first set of motions and graphs to make thoughtful predictions for these motions. *For an egg and cart demonstration of a collision.* Students will enjoy this demonstration, particularly the crash. It will be important for you to focus their attention to the different aspects of the motion and the collision.
How strategy develops science ideas	Predicting and creating motions from graphs and graphs from motions allows student to practice their newly acquired skills in reading graphs and thinking about motion.
How strategy supports student thinking	*For an initial egg and cart demonstration of a collision.* Again students' explanations will be sketchy and use terms incorrectly. These explanations are important to make explicit the ideas that students have about motion to both you and the students
Representations of science concepts How to use the representation	Slope: This is a good opportunity to reinforce the concept of slope. Slope is rise over run or for a change in y there is a corresponding change in x. The greater the change in y for a given change in x the greater the steepness of the line therefore the greater the slope. For our case it means a greater change in position for a certain change in time.
How it represents science ideas to students	This graph further emphasizes that the graphs produced for each motion are plotting two things: time and position. Position being the distance that the student is from the sensor. If the student stands still then their position remains constant and is plotted as such. Time still continues to elapse, so time is plotted resulting in a horizontal line.
How representation supports student thinking	It is important that students see that you are watching the graph as it is being created by the computer. When students create their own motions, if they watch the graph and feel their own motion at the same time they will be able to connect motion to the illustration of the motion much easier.

Table 4 Continued

Description and Examples of Educative Features for Pedagogical Content Knowledge

Types of Educative Features	Examples from Materials
Student thinking Initial understanding and experiences	Many student will think that any object in motion experienced a force at one time and that objects at rest have not experienced a force.
Probable responses and demonstration of understanding	When the egg was moving faster, students may mention that the egg hits harder implying more force is involved when moving faster.
Appropriate level of understanding and challenging ideas.	Another point that may confuse students is the relationship of force to motion. An unbalanced force on an object will cause a change in motion. Some students think that if an object is in motion that there is an unbalanced force on it. This is not true if the object is at a constant velocity.

Teacher Work Sessions

The summer workshops were held daily for two full weeks. Approximately thirty hours were specific to the force and motion unit. An additional thirty hours were spent on general PBS topics such as contextualizing with driving questions and anchoring experiences, setting up and using specific technology tools, using artifacts to assess student understanding, and encouraging collaboration among students. Ms. Franklin and Ms. Cole attended daily during both general and force and motion summer sessions. Ms. Turner attended the initial week of general PBS sessions. Each teacher actively participated in the sessions they attended.

The force and motion sessions covered both content and pedagogy relevant to this unit as well as some specific activities in the unit. Typically teachers engaged in an activity and then discussed what they learned, how the activity would be done with students, and how they activity would support student learning. Teachers also practiced setting up or using equipment, including technology tools. Teachers worked in small groups, discussed ideas, used motion sensors, conducted a ramp and cart investigation modified from the materials, and presented their ideas to their peers.

Saturday sessions were held once a month and were divided between general PBS topics and topics specific to the curricula teachers were enacting. For the force and motion sessions, topics were chosen for their immediate value in the classroom. For example, a review of how to set up and guide students in the use of motion sensors was done during the second Saturday session because teachers were planning to begin using this technology in the following week. Likewise, the first Saturday session included discussion of contextualizing activities and making sure teachers had all the necessary materials and equipment. The third Saturday session was devoted to supporting student presentation and assessing artifacts.

Finally, throughout enactment, each teacher was visited weekly at their school during their planning period. These sessions were personalized and addressed issues of the teachers' choosing, typically specific questions about lessons for the next day or two. Typically teachers would ask for help setting up motion sensors on their computers, ideas for managing student notebooks, or clarification of text in the materials.

Data Collection

One class period throughout the unit for each teacher was videotaped during enactment of this unit. Two teachers were videotaped daily and the third periodically. Teachers were also interviewed just prior to enacting selected lessons and again just after the lesson. Questions targeted plans for instruction, adaptations, and reasons. Sample questions included: How do you envision helping students understand velocity? What would you change about this lesson?, and What did you need to know to make this lesson work? Teachers were also asked what features of the material they found helpful or would recommend and how they used the materials. Questions about the materials and the educative features were also included in an exit interview with all teachers at the conclusion of the unit. All interviews were audio taped. Table 5 lists frequency and amount of data collected for each teacher.

Table 5
Frequency and Amount of Data for Three Teachers

Teacher	Frequency of classroom observation	Hours of video tape	Number of interviews	Hours of audio tape
Ms. Franklin	Daily for one 90-minute period	25	5	2.5
Ms. Turner	Daily for one 2-hour period	15	3	3
Ms. Cole	Periodically, approximately once per week for one 50-minute period	5	7	4.5

Data Reduction

Detailed descriptions of classroom events captured on videotape were written. From these descriptions episodes were identified. The boundaries of an episode were defined as a major change in the activity of the class. For example a typical videotaped class period might consists of three episodes, (a) whole class, teacher lead recitation to set up the task for the day, followed by (b) small group work where students complete the activity or discuss ideas, and finally, (c) whole class, student sharing of ideas. Hence, an episode was a coherent chunk of instruction.

Teachers' practices were coded within these episodes for behaviors or statements consistent with practices recommended in the curriculum materials and addressed by educative curriculum features as described above. We coded episodes for (a) content (ideas presented and the scientific accuracy of the ideas); (b) contextualization (referring to the driving question or anchor ideas, using real life examples, stating value); (c) linking ideas to previous or future lessons or to other ideas; (d) directions; (e) emphasis given such as what ideas or tasks are important; (f) specific strategies such as POE; (g) specific representations such as motion graphs; and (h) teachers' interaction with students (modeling, coaching or feedback). Suggested lessons or portions of lessons that were enacted, omitted, or adapted were also noted as well as evidence of teachers using information offered specifically in educative features of the materials. Summaries of each day were then written from the coded episodes that described enactment in comparison to the recommended practice in the educative materials and used of educative features.

Teacher interviews were also described and coded. Written descriptions were prepared, as in the videotape, based on the curriculum materials and the educative features. We coded the interview descriptions for: (a) accuracy of content; (b) accuracy of pedagogical ideas; (c) thinking about students (student responses, need for support, ideas to assess); and (d) plans for enactment consistent with those recommended in curriculum materials. We also noted what specific educative features teachers referenced and how they used those features. Coded interviews were summarized based on reported use of educative features and plans consistent with practice recommended in educative materials.

Data Analysis

To address our study questions we needed information on three constructs: (a) use of educative materials, (b) teacher knowledge, and (c) linkage between use and knowledge. We were guided in our analysis of both the classroom observation and teacher interview data by analysis questions based on these constructs. Tables 6 and 7 outline the questions that guided analysis. Also listed are the types of evidence within each data type used to answer each question.

To analyze classroom observation data, we combined episodes to find patterns first by teacher then across teachers. We began with the construct of use of educative materials. We looked for evidence within classroom observation data to answer the questions: "Do teachers read and plan from educative materials?" and "Which features do teachers attend to, like and learn from?" We looked for evidence that lessons were enacted, the materials were referenced and specific ideas found in educative features were mentioned. We continued our analysis with the construct of knowledge. The educative features of our materials addressed teacher knowledge within three areas, content, pedagogy, and PCK for each lesson. Therefore, we used the curriculum recommended in the educative materials as a framework to examine teacher knowledge within each knowledge area. Our question in each area was, do enactments and adaptations reflect understanding of recommended practice? Types of evidence for each knowledge area are listed in Table 6.

Table 6
Analysis Structure for Classroom Observations

Construct	Analysis Questions	Types of Evidence
Use of materials (inferred)	Do teachers read and plan from educative materials? Which features do teachers attend to, like and learn from?	• A lesson is enacted • Materials are referenced (read in class, wear, highlighting, notes) • Specific ideas found in educative features are used or mentioned
Knowledge (enactment)	*For each area: Content, Pedagogy, PCK* Does enactment and adaptations reflected understanding of recommended practice?	**Content** • Accuracy of content presentation for each concept of the unit. **Pedagogy** • Linking of ideas across lessons • Use of artifacts to assess student ideas **PCK** • Match of representations to recommended • Match of strategy use to recommended • Appropriate feedback, coaching or modeling of student ideas
Link between use and knowledge	Does practice align with educative features used?	• Match of practice to educative features used • Practice reflects knowledge unique to educative features (beyond summer session)

To analyze teacher interview data we combined interviews to find patterns within and across teachers. Table 7 outlines questions and evidence used to analyze teacher interview data. Again we began with the construct of use, looking for evidence that teachers used the materials, how they used the materials and which features they used. Evidence in this case included self-reports of reading the materials, what they thought about as they read the materials and which features they preferred. We then continued this analysis with the construct of teacher knowledge. As with the classroom observation data we asked if plans and justifications reflected understanding of recommended practices in each knowledge area.

Our reported findings on whether and how teachers use educative materials and content knowledge, pedagogy knowledge and pedagogical content knowledge are based on both classroom observation and teacher interview data. In order to establish a link between the use of educative features and teachers' understanding in each knowledge area we returned to both data sources for evidence. We looked for instances when teachers identified the materials as a source of their knowledge about lessons and used information in materials with students in class. In addition, we compared how the materials were used with how closely the plans and enactments matched the intended curriculum. Finally, we were able to describe differences in how individual teachers used our educative materials and the related differences their practices. This allowed us to make conclusions about the role of educative materials in supporting reform-based practices.

Table 7
Analysis Structure for Teacher Interviews

Construct	Analysis Questions	Types of Evidence
Use of materials (inferred)	Do teachers read and plan from educative materials?	• Reports of reading educative features
	How do they read the educative materials?	• Reports of focus when reading and using strategies (highlighting, thinking about students, comparing)
	Which features do teachers attend to, like and learn from?	• Reports of features preferred
Knowledge (enactment)	*For each area: Content, Pedagogy, PCK* Do plans and adaptations reflect understanding of intended practice?	**Content** • Accuracy of content presentation for each concept of the unit. **Pedagogy** • Linking of ideas across lessons • Use of artifacts to assess student ideas **PCK** • Match of representations to recommended • Match of strategy use to recommended • Appropriate feedback, coaching or modeling of student ideas
Link between use and knowledge	Do teachers attribute practice to educative features?	• Match of practice to educative features used • Practice reflects knowledge unique to educative features (beyond summer session)

Findings

Below we first describe how each teacher used the educative features of our curriculum materials. Second we describe patterns of use across teachers. Third we describe teachers' understanding of content, pedagogy and pedagogical content knowledge in reference to recommended practices. The link between use and knowledge is described concurrently in each knowledge area.

Individual Teachers

Ms. Franklin, in addition to becoming familiar with the lessons, read the materials to learn what or how students would think about content ideas during lessons. She described thinking about what a student might think during a lesson as she read the materials. She also thought about how the lesson would help students understand a concept or what they might have trouble understanding. In reference to reading a lesson about motion sensors and graphs she stated, "what I do when I read it, I got the big idea then I work through this again in my mind and say now if I were a student and I didn't have all this information what would I think. Then I jot that down for myself." Ms. Franklin also reported and demonstrated through practice intensive use of our materials, both in general as well as the educative features for each lesson throughout the unit. She also indicated having read the materials carefully by asking for clarification of what was written in the teacher's materials. Her materials were worn and always present during class.

Ms. Cole also read the materials and paid attention to information about students but focused on how students would react or behave during lessons. She thought about what she could expect students to do in response to lessons as she read the materials. "I like how some of the comments are, your students may say so and so, I think that is helpful for someone who is doing this for the first time." She also seemed to expect the activities and student sheets to take the lead in supporting student learning. "They know POE [prediction-observation-explanation], I want them to just do it themselves. I want them to be more responsible for their learning, that's their job." Ms. Cole also stated that she read all of the material offered throughout the unit and was usually seen referring to her materials before and during class.

Ms. Turner also used the materials at the beginning of the unit; however, early on she began to rely on the student worksheets as a guide rather than the teacher's materials. When she read the materials she did so to learn what she would need students to complete during lessons. She said she did this because it was easier to find out what she should make sure students completed. "Before class I would look at the student sheets. They have what the students will be doing. With this book [teacher's materials] you have to read a couple of pages before to figure out what is going to happen that day." Ms. Turner reported that when she did refer to the materials, content support was the most important feature for her. Her materials contained many highlighted and circled passages in the first several sections but were set aside midway through enactment of this unit.

Teachers' Use of Educative Materials

Each teacher reported using the educative materials to help them understand the intended instructional practices and science content. We also have evidence from classroom enactment that teachers used educative features offered in the materials. Teachers used specific information, given in educative features, with their students in class. For example one teacher stated to the class "I know that some of you are thinking that the increasing the mass will cause the cart to go faster." This information was part of an educative feature on how students think about acceleration due to gravity. Each teacher was also emphatic about the fact that they were much more focused on the materials when they were reading them immediately prior to enactment. "If I say they're [the materials] not as helpful it is because I read them in isolation, it doesn't hold my attention and everything as much as if I was getting ready to actually do this." This teacher had read the materials on Saturday for this conversation on Monday. The lesson being discussed would be enacted on Tuesday morning. Teachers also mentioned that the educative features specific to the lesson at hand were particularly helpful such as what students' computer generated graphs would look like and how the graphs would illustrate slow, medium and fast motion. Suggestions for additional educative features were usually for features embedded with lessons. However, most suggestions were for additional resources such as transparencies or easier to read formats such as pictures of student sheets included in teacher's materials.

Teachers' Content Knowledge

With respect to the areas of teacher knowledge, each teacher demonstrated different levels of understanding physics content, pedagogy related to project-based science practices, and PCK, but some general patterns were evident. In the area of physics content understanding, which was supported at the beginning of each learning set, some teachers were more proficient than others but all struggled with more complex ideas. For instance, teachers generally understood velocity, were able to talk about it accurately and gave many appropriate examples. "When your parents are driving you to school, when they are late they go faster. They cover a greater distance in an amount of time." This teacher also sketched a position-time graph on the board with two positively sloped lines and explained, "the steeper one is faster, the steepness indicates how fast you were going." However, she then struggled with the difference between velocity and speed. "If they were going backward that would not be velocity, backing up the car. Speed cannot be velocity when going backward. Velocity can go backward. Positive velocity is related to speed." This teacher had obviously read the content support describing the directionality of velocity but without complete understanding. Other teachers also gave evidence, as this example shows, of using content explanations for the teacher with their students in class even though the explanation went beyond what was suggested for students. However, when teachers were working with students and their resulting graphs, content explanations were more direct and clear. Interestingly, teachers also reported learning specific content from notes about how students may understand a particular science idea. One teacher said she learned about physics from reading the notes about students' misconceptions because she held some of those same misconceptions herself. Each teacher also noted that the content explanations were a good reference because they were easier to read and locate than a physics text.

Teachers' Pedagogical Knowledge

There also was variation in the level of pedagogical understanding. Support for understanding the sequence and flow of the lessons and how content ideas and skills were developed and connected was extensive. This support was offered for the unit as a whole, for each learning set and for each lesson. However, teachers in general did not report reading these descriptions. While teachers were concerned about their own understanding of physics content they did not show the same concern for understanding the underlying pedagogy of how the unit would develop those ideas. Teachers' practices also indicate that they had difficulty connecting ideas from different sections of the unit. They did not necessarily see opportunities to discuss content other than the targeted ideas of the lesson and treated each content idea as discrete. One tool used to connect ideas in this unit was the driving question. Teachers would refer to the driving question by asking, "how does this idea relate to the driving question." Rarely did they ask how does this concept, which helps to answer the driving question relate to this previous concept, or what does our question guide us to think about next. Concept mapping, an important activity repeated three times across the unit to support students in developing connections between concepts was the most often omitted activity. This was in part due to teachers' unfamiliarity with concept mapping. However teachers were also unfamiliar and uncomfortable with computers, yet none of the activities using computers were omitted by anyone. Technology-based lessons each introduced and explored specific content ideas. Concept maps integrated ideas already introduced.

Ms. Franklin was the only one to mention reading the overviews and thought they were good. She also was the only teacher to use concept mapping. On the first occasion she spent three days with her class developing concept maps and encouraging students to relate ideas, "I want to see lots of relationships." After this lesson she stated that she and her students thought they understood everything about Newton's 1st law, but they did not really understand it until they created their concept maps. Unfortunately, later in the unit when time had become an issue she did not return to this activity.

Teachers had similar difficulties with assessment through artifacts. Three main artifacts were to be developed by students throughout the unit to support students in developing their ideas and to demonstrate these ideas to teachers. Again educative features addressing artifacts were included both before and after lessons. The role of each artifact, when and how students should develop them, and how they would demonstrate student understanding was explained. One of these was the concept maps discussed above. The other two were an investigation of an egg helmet and a 5-part essay describing force and motion. The essay was used by all teachers at the beginning and end of the unit but not revisited during the unit. Everyone completed the investigation during the last days of the unit. Teachers did not appear to understand the role of developing artifacts over time.

They also did not see artifacts as assessment opportunities until the end of the unit. Ms. Franklin understood what students should be able to do in a lesson and monitored each student regularly. Ms. Cole read the materials describing what students' velocity-time graphs would look like, how graphs could be read to interpret changing motion and how students would respond if they understood the graphs. When asked how she would be able to know if students understood the graphs when she did this lesson on the next day, she was able to describe what questions she could ask and what she would expect students to answer. But when asked if she planned to do this she paused then said "I guess I could do that, maybe, now that you mention it maybe I should do that. Maybe I will." Although she understood the representation and student ideas (PCK) she did not understand assessment, that this was an assessment opportunity, or that she should monitor students understanding prior to the end of the unit. Ms. Turner created traditional quizzes to supplement the unit, in part as behavior management technique.

Teachers' Pedagogical Content Knowledge

In the area of PCK, supported by embedded notes within a lesson, teachers were able to use specific strategies and representations with their classes. Teachers were generally successful in contextualizing individual lessons with real life examples and referring to the driving question as described above. Specific strategies, such as prediction-observation-explanation, and specific content ideas, such as velocity, to be represented were explained in notes to the teacher as well as how students might use this lesson to build understanding. Teachers who read these materials could describe how POE could support student learning although the experienced teacher was more skillful in enacting the POE cycle. Both Ms. Franklin and Ms. Cole described the value of explaining an observation then using that knowledge to make the next prediction. Ms. Franklin pressed her students to think about what they just learned when making the next prediction. Ms. Cole asked her students to predict, observe then explain did not monitor students' readiness to proceed before asking students to make the next prediction. By contrast, Ms. Turner who discontinued reading the materials did not appreciate the value of explaining one event before making a prediction about another. Rather than cycles of POE she had students complete a group of predictions then do the activities. The explanations were assigned as homework.

Teachers also used the recommended representations to help students understand ideas. Noteworthy is their use of motion sensors with computer interface. All teachers had little to no previous experience with technology and were initially apprehensive about using computers in their classroom in spite of work during the summer institute. However, each was successful in having students use motion sensors to explore motion and design investigations. Use of motion sensors was embedded in specific lessons to represent specific content with a specific strategy. Teachers were able to use information in the materials to learn how to help their students make sense of the content represented in their graphs. Yet the same pattern among the three teachers described above was seen here also. Ms. Franklin pressed students to think about what they saw on the graphs. Ms. Cole asked students to think about what they saw but moved on to the next lesson before students were ready. Ms. Turner emphasized completion of the motion graphs during class and asked students to explain generic motion graphs at a later time.

Discussion

Few curricula have been developed to be educative for teachers as well as students. But since reform-based curriculum, such as ours, depends on teachers' enactment we were interest in the role of educative curriculum material in supporting reform-based practices in science education. All of our teachers were new to this curriculum, physics, and project-based instruction, yet those who used educative features in the materials were more successful in interpreting the curriculum into practice. Teachers used educative materials most when planning, focused on what they needed to know to enact a lesson with their students, and thus attended to educative features closely related to specific lessons. Interview and observation data both suggested that teachers understood lesson specific ideas (PCK) better than content or pedagogy when using educative materials. Teachers' practices were more consistent with those intended for specific lessons than they were for the unit overall. Teachers used lesson specific educative features, understood lesson specific ideas, and reflected this in changing lesson specific practices.

This finding that teacher used and learned from lesson specific features suggests that pedagogical content knowledge may be a useful construct for designing educative curriculum materials. Teaching is a complex activity that requires teachers to understand content and pedagogy as they come together to support student thinking and learning in the context of their classroom (Magnusson et al., 1999; Shulman, 1987). This is in alignment with others who have found PCK to be an important distinction between expert and novice teachers (Borko et al., 1992; Borko & Livingston, 1989; Clermont et al., 1994). Teachers new to reform-based curriculum need support in learning new representations of content, new strategies to support student construction of knowledge, and to understand students' thinking about science ideas.

Educative materials are uniquely situated in the classroom, unlike other professional development opportunities. To best take advantage of educative materials to help teachers learn would, perhaps, mean addressing knowledge that is also uniquely situated in the classroom. Because curriculum materials by definition are about specific lessons it is more difficult to support content and pedagogy but much easier to support PCK. A discussion of a science concept can quickly leave the specific lesson at hand far behind as the science idea is fully developed beyond the level of suggested student understanding. A similar discussion of underlying pedagogy requires teachers to think about the big picture of the unit as a whole or even many units. But because PCK is so specific to presenting an idea to students utilizing a representation and strategy, a discussion of how students think and respond to a lesson is tied to a discussion of that lesson. This also supports Shulman's (1986) hypothesis that cases can be effective learning tools for teachers. A lesson thus described and explained approaches Shulman's definition of case-based learning for teachers.

This is reinforced by the fact that teachers used these materials to plan for their students in the immediate future. Other, broader areas of teacher knowledge should be addressed in professional development opportunities outside of the classroom. This is in agreement with others who found that teachers attribute learning pedagogy and content in university settings, and pedagogical content knowledge in their classroom based experiences (Borko & Mayfield, 1995; Grossman & Richert, 1988). Because educative features can be embedded in a specific lesson they naturally would address a specific strategy to use with a specific representation of content and how students will think about the lesson. The lesson, with its educative features embedded, is thought about and enacted by teachers with their specific classroom context in mind, thus situating teachers' learning in their own classroom (Borko & Putnam, 1996; Brown et al., 1989).

It is important to recognize that this study was conducted with only three teachers, one of whom stopped reading the materials early on. Therefore, although we have gained some insights, many more teachers will need to participate in using educative materials in order to make conclusions such as ours more convincing. Like others, we also found that how teachers approach educative materials or other professional development opportunities to be an important factor in their learning (Collopy, 1999; Franke, Carpenter, Fennema, Ansell, & Behrend, 1998). Teachers generally do not approach these opportunities thinking that they will change their concept of teaching. Rather they expect to add to their repertoire of activities (Wilson & Berne, 1999).

Experience in teaching was also related to each teacher's practice, but did not fully explain the observed difference. It is true that the teacher with 16 years of experience did make the most of the opportunity to learn, but the teacher who discontinued using the materials had four years experience. The teacher with only one year of experience read the materials and made gains in understanding in each area. Her lack of experience may explain her struggle with putting plans into action and thinking about students' thinking, more than it explains how well the materials were used for planning.

One could also argue that the professional development in the form of summer and Saturday work sessions helped teachers learn how to enact project-based science (Fishman et al., 2000). The work sesssions were essential. During these sessions, teachers were introduced to project-based science, technology tools, and this curriculum unit. However, the areas where teachers had the most success, specific lessons, were the areas less emphasized in the workshop. Moreover, teachers did not have the opportunity to practice these lessons with students during the work sessions. The in-classroom support tended to focus on general topics such as how to operate the computers or manage student notebooks. Teachers' statements about their use of the materials also help to point us to the educative features as a source of some of their understanding. It is more likely that a combination of factors, including the educative support for teachers provided in the materials, contributed to the observed enactments (Blumenfeld et al., 2000). A research design with a greater focus on specific educative features and how teachers think when reading them would give us more information to improve the design such materials (Ericsson & Simon, 1993).

Educative curriculum material appears to be a promising approach to facilitate teacher learning that is necessary for improved practice. In order to create such materials, however, much research needs to be done. We have little empirical evidence to guide us in the development of such materials. This study begins to identify what knowledge is best conveyed with educative curriculum materials and how teachers might use these materials. Further research in this area along with studies on required prerequisite skills or knowledge and how student learning is enhanced when teachers use educative materials is needed. This research will inform the development of materials for all teachers as well as those participating in urban reform.

References

Apple, M. W., & Jungck, S. (1990). "You don't have to be a teacher to teach this unit": Teaching, technology, and gender in the classroom. *American Educational Research Journal, 27*, 227-251.

Ball, D. L., & Cohen, D. K. (1996). Reform by the book: What is—or might be—the role of curriculum materials in teacher learning and instructional reform? *Educational Researcher, 25*(9), 6-8,14.

Blumenfeld, P. C., Fishman, B. J., Krajcik, J. S., Marx, R. W., & Soloway, E. (2000). Creating usable innovations in systemic reform: Scaling-up technology-embedded project-based science in urban schools. *Educational Psychologist, 35*(3), 149-164.

Blumenfeld, P. C., Marx, R., Patrick, H., & Krajcik, J. (1996). Teaching for understanding. In I. F. Goodson (Ed.), *International handbook of teachers and teaching*. Dordrecht, The Netherlands: Kluwer Academic Publishers.

Borko, H., Bellamy, M. L., & Sanders, L. (1992). A cognitive analysis of patterns in science instruction by expert and novice teachers. In H. Munby (Ed.), *Teachers and teaching: From classroom to reflection* (pp. 49-70). London: The Falmer Press.

Borko, H., & Livingston, C. (1989). Cognition and improvisation: Differences in mathematics instruction by expert and novice teachers. *American Educational Research Journal, 26*, 473-498.

Borko, H., & Mayfield, V. (1995). The roles of the cooperating teacher and university supervisor in learning to teach. *Teaching and Teacher Education, 11*, 501-518.

Borko, H., & Putnam, R. T. (1996). Learning to teach. In D. C. Berliner (Ed.), *Handbook of educational psychology*. New York, NY: Macmillan.

Brown, J. S., Collins, A., & Duguid, P. (1989). Situated cognition and the culture of learning. *Educational Researcher, 18*(1), 32-42.

Carter, K. (1990). Teachers' knowledge and learning to teach. In W. R. Houston (Ed.), *Handbook of research on teacher education* (pp. 291-310). New York, NY: Macmillan Publishing Company.

Clermont, C. P., Borko, H., & Krajcik, J. S. (1994). Comparative study of the pedagogical content knowledge of experienced and novice chemical demonstrators. *Journal of Research in Science Teaching, 31*, 419-441.

Collopy, R. (1999). *Teachers use of and learning from curriculum materials.* Unpublished doctoral dissertation, University of Michigan, Ann Arbor.

Ericsson, K. A., & Simon, H. A. (1993). *Protocol analysis: Verbal reports as data* (revised ed.). Cambridge, MA: MIT Press.

Fenstermacher, G. D. (1994). The knower and the known: The nature of knowledge in research on teaching. In L. Darling-Hammond (Ed.), *Review of Research in Education* (Vol. 20, pp. 3-56). Washington, DC: American Educational Research Asociation.

Fishman, B., Best, S., Foster, J., & Marx, R. W. (2000). *Fostering teacher learning in systemic reform: A design proposal for developing professional development.* Paper presented at the National Association of Research in Science Teaching, New Orleans, LA.

Franke, M. L., Carpenter, T., Fennema, E., Ansell, E., & Behrend, J. (1998). Understanding teachers' self-sustaining, generative change in the context of professional development. *Teaching and Teacher Education, 14*, 67-80.

Franke, M. L., Carpenter, T., Levi, L. W., & Fennema, E. (1998). *Teachers as learners: Developing understanding through children's thinking.* Paper presented at the American Educational Research Association, San Diego, CA.

Gess-Newsome, J. (1999). Pedagogical content knowledge: An introduction and orientation. In N. G. Lederman (Ed.), *Examining pedagogical content knowledge: The construct and its implications for science education* (Vol. 6, pp. 3-20). Boston: Kluwer Academic Publishers.

Grossman, P. L., & Richert, A. E. (1988). Unacknowledged knowledge growth: Re-examination of the effects of teacher education. *Teaching & Teacher Education, 4*, 53-62.

Guskey, T. R. (1986). Staff development and the process of teacher change. *Educational Researcher, 15*(5), 5-12.

Krajcik, J. S., Blumenfeld, P. C., Marx, R. W., & Soloway, E. (1999). Instructional, curricular, and technological supports for inquiry in science classrooms. In E. V. Zee (Ed.), *Inquiry into inquiry science learning and teaching*. Washington, D.C.: American Association for the Advancement of Science Press.

Krajcik, J. S., Czerniak, C. M., & Berger, C. (1999). *Teaching children science: A project-based approach*. Boston, MA: McGraw-Hill.

Krajcik, J. S., Marx, R. W., Blumenfeld, P. C., Soloway, E., & Fishman, B. (2000). *Inquiry based science supported by technology: Achievement among urban middle school students.* Paper presented at the National Association of Research in Science Teaching, New Orleans, LA.

Magnusson, S., Krajcik, J. S., & Borko, H. (1999). Nature, sources and development of pedagogical content knowledge for science teaching. In N. G. Lederman (Ed.), *Examining pedagogical content knowledge: The construct and its implications for science education* (pp. 95-132). Netherlands: Kluwer Academic Publishers.

Marx, R. W., Blumenfeld, P. C., Krajcik, J. S., & Soloway, E. (1997). Enacting project-based science. *Elementary School Journal, 97*, 341-358.

Pajares, F. M. (1992). Teachers' beliefs and educational research: Cleaning up a messy construct. *Review of Educational Research, 62*, 307-332.

Richardson, V. (1990). Significant and worthwhile change in teaching practice. *Educational Researcher, 19*(7), 10-18.

Ruopp, R. (1993a). LabNet: Toward a community of practice. *Journal of Science Education and Technology, 2*(1), 305-319.

Ruopp, R. (1993b). Students and learning. *Journal of Research in Rural Education Theme issue with title "Telecommunication and Rural Schools: The TERC LabNetwork", 9*, 43-46.

Schneider, R. M., & Center for Highly Interactive Computing in Education. (1999). Why do I need to wear a bike helmet? Ann Arbor, MI: University of Michigan.

Scott, C. (1994). Project-based science reflections of a middle school teacher. *The Elementary School Journal, 95*, 75-94.

Shulman, L. S. (1986). Those who understand: Knowledge growth in teaching. *Educational Researcher, 15(1)*, 4-14.

Shulman, L. S. (1987). Knowledge and teaching: Foundations of the new reform. *Harvard Educational Review, 57*, 1-22.

Singer, J., Marx, R. W., Krajcik, J. S., & Clay-Chambers, J. (2000). Constructing extended inquiry projects: Curriculum materials for science education reform. *Educational Psychologist, 35*(3), 164-178.

TERC. (1995). *Investigations in numbers, data and space*. Palo Alto, CA: Dale Seymour Publications.

Tinker, R. (1996a). The problem of extended inquiry in science teaching: Technology-rich curricula to the rescue. http://www.concord.org: Concord Consortium.

Tinker, R. (1996b). Thinking about science. http://www.concord.org: Concord Consortium.

Tschannen-Moran, M., Hoy, A. W., & Hoy, W. K. (1998). Teacher efficacy: Its meaning and measure. *Review of Educational Research, 68*(2), 202-248.

Wallace, J., & Louden, W. (1998). Curriculum change in science: Riding the waves of reform. In K. G. Tobin (Ed.), *International handbook of science education* (Vol. 1, pp. 471-485). Dordrecht, The Netherlands: Kluwer Academic Publishers.

White, B. Y., & Frederiksen, J. R. (1998). Inquiry, modeling, and metacognition: making science accessible to all students. *Cognition and Instruction, 16*, 3-118.

Wilson, S. M., & Berne, J. (1999). Teacher learning and the acquisition of professional knowledge: An examination of research on contemporary professional development, *Review of Research in Education* (Vol. 24, pp. 173-209). Itascu, IL: FE Peacock Publishers.

Note

More information about this work including the curriculum materials “Why do I need to wear a bike helmet?” used in this study, can be obtained from our project’s web site at this address: http://hi-ce.org/teacherworkroom/middleschool/physics/index.html