JOURNAL OF RESEARCH IN SCIENCE TEACHING VOL. 42, NO. 3, PP. 283–312 (2005)

Enacting Reform-Based Science Materials: The Range of Teacher Enactments in Reform Classrooms

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Received 30 March 2004; Accepted 28 July 2004

Abstract: To promote large-scale science education reform, developers must create innovations that teachers can use to learn and enact new practices. As part of an urban systemic reform effort, science materials were designed to reflect desired reforms and to support teacher thinking by addressing necessary content, pedagogy, and pedagogical content knowledge for teachers. The goal of this research was to describe teachers' enactments in comparison to reform as instantiated in the materials. Four middle school teachers' initial enactment of an inquiry-based science unit on force and motion were analyzed. Findings indicate two teachers' enactments were consistent with intentions and two teachers' enactments were not. However, enactment ratings for the first two were less reflective of curriculum intent when challenges were greatest, such as when teachers attempted to present challenging science ideas, respond to students' ideas, structure investigations, guide small-group discussions, or make adaptations. Overall, findings suggest that purposefully using materials with detailed lesson descriptions and specific, consistent supports for teacher thinking can help teachers with enactment. However, materials alone are not sufficient; reform efforts must include professional development and efforts to create systemic change in context and policy to support teacher learning and classroom enactment. © 2005 Wiley Periodicals, Inc. J Res Sci Teach 42: 283–312, 2005

To promote goals established for student learning, reform efforts in science education have focused attention on classrooms and how teachers can improve their instructional practices. Reformers encourage teachers to use inquiry supported by use of technology tools to promote

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Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author and do not necessarily reflect the views of the National Science Foundation.

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 website (http://hi-ce.org/teacherworkroom/middleschool/physics/index.html).

Contract grant sponsor: National Science Foundation (Center for Learning Technologies in Education); Contract grant number: 0830 310 A605.

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DOI 10.1002/tea.20055

Published online 31 January 2005 in Wiley InterScience (www.interscience.wiley.com).

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student understanding of important science concepts. However, in spite of efforts to support teachers in making instructional changes, these methods remain challenging for teachers to learn and enact (Borko & Putnam, 1996; Wallace & Louden, 1998). In addition, current reforms are being attempted at state and district levels. New ideas for ways to support teachers that are feasible for large-scale use are essential for the success of efforts to enhance student achievement (Darling-Hammond, 1999).

One promising proposal is to include explicit support for teachers to learn about teaching within curriculum materials, making them educative for teachers (Ball & Cohen, 1996). When used in conjunction with other opportunities for teachers to learn about teaching, teacher-educative materials may provide teachers with the tools necessary to enact reforms in their classrooms and promote student learning. Our work in supporting teaching improvement is embedded in a National Science Foundation (NSF)-funded urban systemic initiative to reform science and mathematics instruction in a large urban public school system. In this study we describe what happens in classrooms when teachers are given reform-based science materials, which include explicit supports for teacher thinking, as a key component of a comprehensive effort to support teaching improvement.

Theoretical Framework

Reform-Based Teaching

Reformers interested in improving teaching are encouraging teachers to utilize student-centered instructional practices to actively engage students in activities and conversations that will promote deeper understanding of fewer topics. Reformers are making these recommendations based on ideas about how students learn and what is important for students to know and be able to do. In science, inquiry learning environments are considered essential to engage students in actively constructing deep understanding of science embedded in the everyday world (American Association for the Advancement of Science, 1990; National Research Council, 1996; National Science Teachers Association, 2003). Consistent with social constructivist views of learning, inquiry environments engage students in seeking answers to questions, experiencing phenomena, sharing ideas, and developing explanations (Minstrell & Van Zee, 2000). Evidence indicates that students can attain deeper understanding of science content and processes when they engage in inquiry (e.g., Brown & Campione, 1994; Cognition and Technology Group at Vanderbilt, 1992; Metz, 1995).

Teaching in ways recommended as powerful for student learning, however, will require most teachers to develop new knowledge and skills in teaching (Borko & Putnam, 1996). Inquiry environments support student thinking in ways qualitatively different from traditional science classrooms. Student inquiry is characterized by opportunities for students 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 (Lunetta, 1998; Minstrell & Van Zee, 2000; Roth, 1995). To guide students in their inquiry efforts teachers need to press students to explain, justify, critique, and revise their ideas as they examine their experiences with phenomena. Collaboration and technology tools are considered essential to support students in working with data and ideas in new ways (Blumenfeld, Marx, Patrick, & Krajcik, 1996; McGilly, 1996). To support meaningful discussions teachers need to help students participate in dialogues that require listening, questioning, and responding among peers and teachers. Teachers also need to lead students in using computer technologies that can scaffold their abilities to collect, display, and analyze data and to illustrate and share ideas in ways that encourage thoughtfulness. To create inquiry learning environments in their classrooms, science teachers will need to develop expertise in guiding student inquiry, supporting collaboration, and incorporating learning technologies in ways that address goals for student learning.

Research tells us that teachers find reform-based teaching challenging. For example, when enacting inquiry-based science, teachers face several challenges, including knowledge of: inquiry versus a more linear flow of information; various techniques to promote learning, such as coaching or modeling; specific instructional strategies; classroom management; science understanding of nontrivial content; how to use technology tools to represent content and support inquiry; and nontraditional assessment (Marx, Blumenfeld, Krajcik, & Soloway, 1997; Scott, 1994). Similar challenges are reported in mathematics. Teachers are concerned about covering content, tend to support linear step-by-step computation versus creative problem-solving, and are challenged by the mathematics content (Lampert & Ball, 1998; Putnam, Heaton, Prawat, & Remillard, 1992).

Urban settings present additional challenges for teachers attempting reforms. Large urban school systems are frequently characterized by poverty, a lack of resources, low levels of student achievement, and a disconnect between schools and students' home communities (Barton, 2001; Bouillion & Gomez, 2001). Inquiry can make science accessible by allowing urban students to find greater relevance to their lives while supporting scientific understandings (Songer, Lee, & Kam, 2002). However, teachers may find students resistant to participate in science activities; uncooperative in some types of classroom discourse such as whole-class, teacher-led discussions; or unprepared in skills necessary for inquiry (Barton, 2001; Seiler, Tobin, & Sokolic, 2001; Tobin, Roth, & Zimmermann, 2001). Teachers must attend to their students' needs by making appropriate connections to their students' community, adapting conversations to encourage student participation, and adjusting the pace of lessons (Bouillion & Gomez, 2001; Seiler et al., 2001; Tobin et al., 2001). In urban settings teachers are not only challenged by the complexity of reform-based teaching but also by the complexity of the context in which they are teaching.

Supporting Reform-Based Teaching

Extensive professional development programs have been implemented to support teachers in making changes consistent with reforms. Exemplar programs include opportunities for teachers to talk about subject matter (Thomas, Wineburg, Grossman, Myhre, & Woolworth, 1998), students and learning (Franke, Carpenter, Fennema, Ansell, & Behrend, 1998), or teaching (Lampert & Ball, 1998). However, these programs tend to require time and one-on-one support by researchers or school personnel: typically, several weeks in the summer, in conjunction with monthly sessions spanning 2 to 4 years. Moreover, when teachers' practices are observed, although encouraging signs are seen for some teachers, success is not universal. For example, in a 3-year study of three teachers participating in an intervention effort aimed at changing teachers' beliefs, Meyer (1997) reported mixed results. Although two teachers indicated changes in their beliefs, the practices of only one teacher reflected the belief change. Similarly, Franke et al. (1998) reported little or no change in practices for two of three teachers observed over a period of 4 years. Teachers' knowledge or beliefs do not necessarily predict what they do in the classroom (Wilson & Berne, 1999).

Models that attempt to establish a link from teacher knowledge to practice include linking classroom enactment with reflection on enactment as an essential component of teachers' professional development (Marx et al., 1997; Putnam & Borko, 2000). For example, the CERA model includes cycles of Collaboration among teachers, Enactment in classrooms, Reflection on enactment, followed by Adaptation (Marx, Freeman, & Krajcik, 1998). This model requires teachers to attempt new practices in their classrooms and implies a need for more specific support for instruction. Well-designed reform-based materials that explicitly support teachers' initial attempts to use new instructional practices match this need. Real instructional improvement may be possible when teacher thinking is supported in connection with materials and students (Cohen & Ball, 1999; Putnam & Borko, 2000).

Reform-Based Materials

Materials suitable for the role of supporting teachers in classrooms and as a focus of professional development efforts must first be consistent with reforms, and be effective in supporting student learning. Materials created to promote deep understanding of science ideas feature inquiry as essential for student learning and use technology extensively (e.g., the Cognition and Technology Group at Vanderbilt's [1992], Scientists in Action; Linn's [1998], Computers as Learning Partners; Songer's [2002], Kids as Global Scientists; and White's [1998], ThinkerTools). These programs also claim to promote student learning. However, for materials to support teachers in making the initial attempts at reform necessary for teachers to reflect on and learn from classroom experiences, teachers must be able to translate materials into practice in their classrooms (Cohen & Ball, 1999). Although materials are created to initiate changes on a large scale, directions alone are not sufficient for most teachers to implement effective practices (Anderson, 1995; Franke, Carpenter, Levi, & Fennema, 1998; White & Frederiksen, 1998). Approaches with ambitious learning goals for students remain complex and challenging to enact (Anderson, 1992; Van Den Akker, 1998).

To support teachers in the changes necessary to affect reform, Ball and Cohen (1996) proposed that curriculum materials be designed as educative for teachers. Such materials would offer teachers explicit support for learning about teaching as they use the materials to foster student learning. Although it is not intended that educative materials replace other professional development opportunities, they are situated to play a unique role in supporting teachers. Materials are already in place in schools; teachers are accustomed to using materials both for planning and with their students in the classroom (Ball & Cohen, 1996). Remillard (2000) built on this idea to suggest that educative materials can support teachers in learning how to make informed instructional decisions by leaving "space" for teachers to take an active role in creating instruction. This happens when materials offer tasks to engage students that also make students' thinking visible to teachers. Teachers learn about their students' developing understanding and then can return to the materials for further assistance based on their understanding of students' needs. If materials were educative for teachers in addition to providing instructional guidance, improved instruction could be facilitated on a large scale. This vision, however, is dependent on development of specific ideas for design of materials to meet teachers' needs for learning and enactment support.

What we know about teaching suggests reform materials should assist teachers in instruction, support their learning, and facilitate instructional decisions in ways consistent with teachers' thinking during enactment. Research tells us accomplished teachers have a knowledge base that includes content, pedagogy, and pedagogical content knowledge (PCK) held in integrated, accessible schema (Borko & Putnam, 1996). Teachers think about teaching in episodes or stories (Shulman, 1986) and make many on-demand decisions in the classroom (Borko & Shavelson, 1990). These ideas imply materials can be designed to assist teachers in instruction by linking content ideas with instructional strategies and presenting these ideas within lessons. Teacher learning is supported when information—content, pedagogy, and PCK—is accessible. Materials can explicitly present ideas within detailed, illustrative descriptions of lessons, creating stories. Embedding material explicitly for teacher learning is a new idea. Teachers will need cues to help them recognize when content is intended for their learning (Collopy, 1999). To facilitate adaptation, materials will need to leave room for teachers to participate in instructional decisions to meet the needs of their unique context (Remillard, 2000).

Well-designed, reform-based materials can be a key component of efforts to support teacher change. Such materials can be a focus of discussions exploring ideas for how to put reforms into practice, guides for initial attempts in classrooms, and targets of adaptations based on classroom experiences. For example, CASES is a web-based resource to support new elementary teachers in adapting and using inquiry science units (Davis, 2002). Teachers can select units intended to be educative for teachers to support their initial attempts at inquiry teaching and participate in online discussions about science and science teaching. Others are using materials to engage teachers in thinking about teaching and learning by adapting inquiry units to match their local context (Chang, Honey, Light, Moeller, & Ross, 1998; Spillane, Diamond, Walker, Halverson, & Jita, 2001). Reform materials designed for teachers can be part of a larger package of support that may include summer institutes, efforts to establish learning communities among teachers, or web-based resources.

Reform-Based Enactments

Some of the new curricular programs are embedded in systemic school reform and are key components of efforts to scale reforms throughout a school system (Blumenfeld, Fishman, Krajcik, Marx, & Soloway, 2000). Systemic models for reform appear to hold some promise for improving student outcomes (Chang et al., 1998; Kahle, Meece, & Scantlebury, 2000). However, reports of gains in student achievement do not describe how individual teachers respond to reforms or what happens in specific classrooms. Thus, we do not know the range of reform enactments or how to support a variety of teachers in making changes. To answer these questions and continue to make progress in understanding how to promote instruction improvement on a large scale it is essential to examine reform teaching in classrooms (Anderson & Helms, 2001).

Efforts are currently underway to study how new reforms, and specifically reform materials, influence teachers' practice in the classroom. These studies, although focused on enactment of curriculum materials, are not framed by fidelity models wherein it is assumed success means step-by-step match to the materials, or are considered successful only when the teachers carried out the changes as directed (Snyder, Bolin, & Zumwalt, 1992). Rather, enactment models, which acknowledge teachers as professionals who need assistance with instruction, are used to examine the consistency or congruence of classroom events with reform practices as instantiated in materials. The materials themselves are not considered complete until teachers interact with them to create instruction (Cohen & Ball, 1999; Remillard, 2000). This means that, although equivalence to reform materials is measured, it is not necessary for enactments to demonstrate strict fidelity to the materials in order to be judged consistent with the intent of reforms. Instead, variations in enactments that meet student learning needs are considered reflective of reform and consistent with the intent of the materials. Examples include studies of teacher change as well as studies focused on student learning in reform classrooms (Collopy, 1999; Pinkard, 2000; Prawat, 1992; Remillard, 1999; Rivet, 2003). These studies include description of classroom events in relation to reform goals as described in curriculum materials and are useful in capturing the range of enactments within reform.

Materials in Urban Systemic Reform

In our work we are attempting to support teaching improvement as part of an ongoing systemic initiative of a large urban public school district to reform science and mathematics instruction. To promote instructional improvement, science materials were developed to reflect desired reforms and provide teachers with needed support to learn and enact an innovative curriculum. These materials were the focus of other professional development opportunities provided in conjunction with the reform effort.

Inquiry science materials were developed based on the premises of project-based science (PBS). In project-based science, students engage in extensive use of student-directed scientific inquiry supported by technology and collaboration (Krajcik, Czerniak, & Berger, 2002; Ruopp, 1993; Tinker, 1996). Four key features of PBS are identified: (1) a driving question encompassing worthwhile content that is meaningful and anchored in a real-world problem; (2) investigations and artifact creation that allow students to learn concepts, apply information, and represent knowledge; (3) collaboration among students, teachers, and others in the community; and (4) use of technology tools. We have evidence that PBS learning environments promote student success in science (Schneider, Krajcik, Marx, & Soloway, 2002; Stratford, Krajcik, & Soloway, 1998).

To support teachers in science reform and launch a scalable and sustainable method to promote teaching improvement in an urban systemic effort, materials for several PBS units were developed. Developers were guided by design principles that include: contextualization; alignment with standards; sustained student inquiry; embedded learning technologies; collaboration and discourse; assessment techniques; and scaffolds and supports for teachers (Singer, Marx, Krajcik, & Clay-Chambers, 2000). Materials were designed to address important science ideas, offer multiple learning opportunities, and provide appropriate instructional supports for students. We have evidence that these units can help students learn science (Krajcik, Marx, Blumenfeld, Soloway, & Fishman, 2000; Rivet, Krajcik, Marx, & Riser, 2003).

Professional development opportunities were designed to support reform teaching consistent with the science materials. Teachers are given opportunities to talk about inquiry science and student learning in connection with lessons described in the units (Fishman, Best, Foster, & Marx, 2000). The materials themselves also were designed to support teacher thinking (Schneider & Krajcik, 2002). Materials include detailed lesson descriptions to assist teachers in enactment. Features to address the learning needs of teachers offer information to explain content and pedagogy, as well as specific information about strategies, representations, and students' ideas (PCK) embedded within lessons. Teachers also are encouraged to modify the curriculum to meet the needs of their students and circumstances. In this study we examine initial attempts to enact science reforms by teachers using these materials.

Purpose of the Study

With the amount of attention given to the design of materials to instantiate science reform and the interconnected support for teachers to learn and enact reform it is reasonable to ask: What happens in classrooms? Because the materials were developed to exemplify reform practices in science and to enable teachers to attempt new practices in their classrooms, we wondered if teaching would look like reform as described in the materials. To guide our research we asked: *When teachers are given reform-based curriculum materials and support for teacher thinking around and within the materials, what does classroom enactment look like in comparison to the intent of the materials?* The answer to this question is a description of classroom enactments. We were interested in whether teachers did the activities with their students but also the manner in which the lessons were enacted. Would these classrooms look and sound like what we envisioned for reform classrooms? In addition, we wanted accounts that described the variation in how reforms are enacted. How did teachers understand the materials and customize their enactments to make reform work in their classroom? Detailed descriptions that answer this research question can guide efforts to develop effective materials and supports for all teachers in reform.

Methods

Background

This study was embedded in a NSF-funded urban systemic initiative to reform science and mathematics instruction in a large midwestern urban public school system. As a systemic effort, changes were being attempted at all levels of the school system; teachers' instructional practices were only one facet of the change process under study (Blumenfeld et al., 2000). This study was conducted in four urban middle schools located in low socioeconomic status (SES) neighborhoods selected to participate in initial stages of the reform effort. Schools were selected for participation by the district representative and were chosen with the approval of the building principal because they were regular neighborhood schools with some computer resources. Students in these schools were predominantly African American (95% to 100%), with high percentages of students receiving free or reduced-price lunch (29% to 66%). Scores on local and statewide achievement testing in science were reported as below grade level in three of the four schools.

Curriculum material development was considered an essential component of the change effort, particularly to facilitate change within classrooms on a large scale (Singer et al., 2000). The project-based science curriculum materials used by teachers in this study were developed as part of the larger reform effort. As a researcher and curriculum developer for the project, the first investigator (R.M.S.) took a lead role in designing these materials to support both students and teachers in the transition to inquiry-based science instruction. However, the features of the materials intended to support teacher thinking were only one part of the professional development involved in this reform effort (Fishman & Best, 2000).

Teachers. 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 in the

Table 1
Background and experience of teachers participating in this study

	Ms. Franklin	Ms. Wells	Mr. Davis	Ms. Turner
Preparation	B.A. education—elementary science and social studies M.A. education—mathematics	B.A. education—elementary science and social studies	B.A. chemistry M.A. education—mathematics	B.A. education—secondary biology and physical education, M.A. educational administration
Certification	Elementary, all subjects K–8	Elementary, all subjects K–8	Math and science grades 7–12	Science grades 7–12
Teaching experience	16 years middle school science	20 years middle school, 3 years science	10 years middle school, primarily science	4 years middle school science
Project related experience				
PBS	First year—fall 1998	Third year—fall 1999 (First year force & motion unit)	First year—fall 1999	First year—fall 1998
Physics content—self reported	Moderate	Limited	High (chemical process engineer)	Limited
Technology tools	Limited	Model-It, dynamic modeling software	Limited	Limited

larger reform effort. Teachers were selected for observation based the unit they were enacting and times the researchers could visit classrooms. For this study, teachers enacting the force and motion unit for the first time in several of their classes were selected for observation. Because data collection involved substantial time in the classroom to record video, two teachers were observed during the fall term of 1998 and an additional two teachers in the fall of 1999. Teachers were introduced to the unit at a 2-week summer institute and were supported by monthly professional development workshops as part of the reform effort. With the exception of Ms. Wells, this was their initial experience with the reform project. Ms. Wells had taught two other units developed by the reform project. Initially, Mr. Davis was the only teacher comfortable with physics content. Prior to enacting this unit, each of the four teachers had limited experience with one or more of the following aspects: project-based science; physics; or the use of technological tools to support inquiry. Although they were not selected as a statistically random sample, their disparate backgrounds made them representative of middle school science teachers across the district.

Ms. Franklin, Ms. Wells, and Mr. Davis reported a thorough reading of all the materials throughout the enactment. Ms. Turner also reported reading all of the materials at the beginning of the unit; however, midway through the unit she began to rely on the student worksheets as a guide rather than the teacher materials. Each teacher also demonstrated that they had read the materials carefully by asking specific questions about what was written in the teacher materials or by making statements during class that included specific information from the educative features of the materials. In addition, the condition of the teacher materials indicated use. Ms. Franklin's and Ms. Wells's materials were worn, highlighted, and always present during class. Ms. Turner's materials also contained many highlighted and circled passages in the first several sections, but were set aside midway through enactment of the unit. Although Mr. Davis did not make notes in the materials themselves, the materials were always present during class. He also reported that he read "every word." The fact he was able to point out the typographical errors in the materials backs up his statement.

School context. All science classes met for approximately 5 hours per week, but schedules varied by school. Ms. Turner and Ms. Franklin both taught in schools with block schedules, with science classes meeting three times per week. However, Ms. Turner's class met for a different amount of time each day and at a different time of the day (i.e., morning versus afternoon). Ms. Franklin's class met during the same time slot each day, with 3 days devoted to science and 2 days devoted to an engineering-focused enrichment program. In a given week, Ms. Franklin had the flexibility to choose which days would be devoted to science. Mr. Davis and Ms. Wells both met with their classes daily for 50-minute sessions. However, Ms. Wells's class was split into two 25-minute segments with a lunch period in the middle. Mr. Davis devoted two class sessions each week to electricity and magnetism topics to satisfy other curriculum objectives.

Ms. Franklin and Ms. Wells had access to computers in their classroom. This afforded them flexibility to use computers at any time as well as allowing some students additional time with the computers while other students completed non-computer tasks. Ms. Turner and Mr. Davis had to schedule time for their class to visit the computer lab. In addition, Mr. Davis had to arrange for the computer room to be unlocked before escorting students there. Ms. Turner had the concern of not disturbing students in the adjacent library.

Curriculum materials. The curriculum materials used in this study were developed to involve eighth grade students in an 8-week extended inquiry. Students investigated the driving question, "Why do I need to wear a bike helmet?" (Schneider & Center for Highly Interactive Computing in Education, 1999). Lessons were designed to help students develop understanding of Newton's first law, velocity, changing velocity, and force as well as graph interpretation and experiment design. The lessons integrate use of motion sensors with computer interface and emphasize collaboration among learners. Students create various artifacts to both develop and demonstrate their understanding.

The curriculum materials included teacher materials and student worksheets. In the teacher's material, the unit was divided into five sections called learning sets, based on main ideas. Each learning set consisted of several 1- to 3-day lessons. Teacher materials included detailed descriptions of lessons and explicit support for teacher thinking in the areas of content, pedagogy, and pedagogical content knowledge (see Schneider & Krajcik, 2002). Information intended for teachers was identified by labels such as ‘‘science understanding for the teacher’’; icons such as a light bulb for content explanations connected to student activities; or special formatting such as italics for notes describing student ideas within lessons.

Descriptions detailed the intended structure and flow of each lesson. Often, short scenarios in the voice of a teacher or students were included to illustrate how an idea or activity may be introduced in connection to other ideas. The targeted science content was clearly identified and connected to the driving question of the unit. Descriptions of science representations, instructional strategies, and student investigations were thorough. Appropriate instructional supports were suggested throughout and included ways to guide students in doing tasks, focus student attention on important events or ideas, or guide student thinking.

Content support was offered before each learning set to help teachers understand Newton's first law, velocity, changing velocity, and force, as well as reading and interpreting motion graphs and investigation design. This support was two to three pages in length, describing both concepts and process ideas with diagrams and examples. In addition, content information was included within lessons to explain lesson-specific content.

Pedagogical support explained the sequence and flow of the lessons and offered general ideas about alternative assessment through the artifacts in this unit. 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. Explanations of how students use ideas to develop artifacts that could be assessed for understanding were offered both before and after lessons.

Features to address pedagogical content knowledge (PCK) were embedded within each lesson. These supports targeted: (1) how to use the specific strategy, how it develops science content ideas, and how it supports student thinking; (2) how to use the specific representation, how it represents science content ideas, and how it supports student thinking; and (3) examples of student ideas that were likely to emerge, including probable prior knowledge and experiences, challenging concepts, probable responses and demonstrations of understanding, and appropriate level of student understanding.

Worksessions. The summer workshops were held daily from 9:00 a.m. to 2:30 p.m. for 2 full weeks. Approximately 20 hours were specific to the force and motion unit. An additional 20 hours were devoted to general project-based science 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. Attendance for force and motion sessions ranged from an average of three teachers in 1998 to ten teachers in 1999. This reflects the increase in schools participating in the reform effort due to efforts to ‘‘scale-up’’ the reform. Ms. Franklin, Mr. Davis, and Ms. Wells attended daily during both general and force and motion summer sessions. Ms. Turner attended only the initial week of general project-based science 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 how to do some of the specific activities in the unit. For example, the materials describe five demonstrations using repeated cycles of predict–observe–explain to illustrate Newton's first law. To shorten the activity and make it more appropriate for adults, teachers participated as learners of science in one of the five demonstrations. Typically, teachers engaged in an activity and then discussed what they learned, how the activity would be done with students, and how the activity would support student learning. Teachers also practiced setting up or using the equipment, including the technology tools. For example, time was allotted for each teacher to practice using the ballistic cart. Teachers worked in small groups, discussed ideas, used motion sensors, conducted an investigation, and presented their ideas to their peers.

Saturday sessions were held once per month, also from 9:00 a.m. to 2:30 p.m. Like the summer workshops, all teachers participating in the reform effort were invited. Generally, the teachers in this study attended these sessions. Saturday sessions, like those in the summer, were divided between general PBS topics and topics specific to different curricula that teachers were enacting at the time. 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 a 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. Each of these topics was initially addressed in the summer sessions.

Finally, throughout the enactment, each teacher was visited weekly at his or her 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. Teachers would ask for help setting up the motion sensors on their computers or help clarifying items in the materials. Sometimes they would relay stories about interesting events involving students and the unit activities.

Data Collection and Preparation

The primary data source for this study was classroom enactment recorded on videotape. One class period for each teacher was selected and videotaped during enactment of this unit. Two teachers were videotaped daily during the fall of 1998. In the fall of 1999, two additional teachers were videotaped two or three times per week. Sections were chosen for observation based on compatibility with times staff could be in the school to collect data and provide support.

Target lesson sequences. Five target lesson sequences, evenly spaced across the 8-week unit, were identified for study. The selected lesson sequences included: (1) ballistic cart demonstrations—experience phenomena; (2) ramp-and-cart investigation—investigation; (3) "how fast is fast?" motion graphs—technology; (4) changing motion indicators—experience phenomena; and (5) helmet testing and presentation—artifacts. Each lesson sequence spanned 2 to 6 days, depending on the nature of the lesson and time available during one class period. Each lesson sequence highlighted a different aspect of inquiry teaching. Because the materials were designed to be educative, lessons were selected from across the 10-week duration of the unit, to allow time for possible teacher learning. In addition, how each lesson sequence was supported by educative material for teachers was considered in the selection process.

The materials for the first three lesson sequences included abundant information both before and within the lesson sequence descriptions. However, the materials for the fourth and fifth lesson sequences had less information embedded in the descriptions. The materials were written this way to fade support for information that would have been repetitive regarding specific strategies and representations addressed in earlier lessons. In addition, information supporting these two lesson sequences was included throughout the materials as it was intended that students would develop their artifacts over time. These lesson sequences were included in this analysis to facilitate later interpretation of the benefits of the materials to support teachers. Like the first three, these lesson sequences were supported by general content and pedagogy information prior to the lesson sequence description.

Enactment descriptions. Detailed descriptions of classroom events were written from the videotape for each target lesson sequence and teacher. Teacher and student behavior and conversation were described in light of the lesson sequence descriptions in the materials. As these descriptions were prepared, we looked for and described: (1) science ideas (content and process ideas presented); (2) contextualization (referring to the driving question or anchor ideas, using real-life examples, stating value); (3) linking ideas to previous or future lessons or to other ideas; (4) directions given; (5) emphasis given—such as what ideas or tasks are important; (6) specific strategies such as predict–observe–explain (POE); (7) specific representations such as motion graphs; (8) scaffolding (modeling, coaching, feedback, or asking for justifications or reasons); and (9) group work (teacher statements on group work, teacher role during group work). We also noted suggested lesson sequences or portions of lesson sequences that were enacted, omitted, or adapted and evidence of teachers using information offered specifically in educative features of the materials.

Data Analysis

The coding scheme used was designed to capture three aspects of enactment—presentation of science ideas, opportunities for student learning, and support to enhance the learning opportunities—each in comparison to what was intended in the materials. Coding schemes used in this analysis were developed through an iterative process of creating codes, coding, modifying and refining codes, and recoding consistent with Miles and Huberman's (1994) recommendations for rigorous and meaningful qualitative data analysis. The independent coding of several enactment episodes by another science education researcher assessed reliability of the coding process. Ratings assigned by each researcher were compared in each of the eight categories. Reliability was determined by dividing the number of ratings that were identical by the total number of ratings possible. Reliability was 88%. This was considered acceptable due to the high level of agreement; most ratings were identical and discrepancies were within one rating level of matching. After the categories and rating levels were finalized and reliability established, all enactment data were recoded with the final codes.

The final coding scheme assessed instructional events in the following eight rating categories: *accuracy* and *completeness* of science ideas presented; amount of student learning *opportunities*; *similarity* of learning opportunities to those intended, and quality of *adaptations*; and the amount of *instructional supports* offered, *appropriateness* of instructional supports, and the *source* of ideas for instructional supports. Each enactment episode was rated in each category according to the descriptions listed in Table 2 for each rating level. The entire episode and the type of activity were considered when assigning a rating in each category. A short statement of evidence or justification was written for each assigned rating.

Enactment descriptions were coded first by episode of instruction, then across enactment episodes for each target lesson sequence within a teachers' enactment. Ratings and justification statements in each category were compared sequentially to make a judgment of a rating for the entire lesson sequence. A justification statement also was written for each lesson sequence rating based on a summary of the individual statements. When individual ratings varied, care was taken to write summary statements that appropriately reflected the variation. When variation was pronounced, two or more ratings were assigned, the lesson sequence was labeled as varied, and the variation was described in the justification statement. Finally, each rated lesson sequence was examined for patterns across lesson sequences and teachers.

Table 2
Categories and rating levels of coding scheme used to analyze classroom enactment data

Accuracy
Scientific—all ideas are consistent with current scientific ideas
Sufficient—consistent with current scientific ideas for all main ideas, inaccurate for minor ideas
Semiaccurate—inconsistent with current scientific ideas for some main ideas
Nonscientific—inconsistent with current scientific ideas for many main ideas

Completeness
Thorough—all the appropriate science ideas are addressed
Sufficient—all the appropriate main ideas are addressed but some minor ideas are missing
Incomplete—missing some main ideas
Insufficient—missing several main ideas
Excessive—includes ideas at a level beyond intended for students

Opportunities
Maximum—includes ample (number or time) opportunity for student learning
Sufficient—includes some (number or time) opportunity for student learning
Insufficient—includes few (number or time) opportunity for student learning
Minimal—includes almost no (number or time) opportunity for student learning

Similarity
High—matched to intended lesson
Medium—closely resembles intended lesson, minor changes
Low—faintly resembles, major changes
None—not consistent with intended lesson

Adaptation
High—adaptation consistent with learning goal and appropriate for students' learning needs
Medium—adaptation consistent with learning goal but not appropriate for students' learning needs
Low—adaptation not consistent with learning goal
None—not adapted

Instructional supports
High—provides many instructional supports for student thinking
Medium—provides some instructional supports for student thinking
Low—provides few instructional supports for student thinking
None—provides no instructional supports for student thinking

Appropriateness
Excellent—instructional supports always used in ways matched to student learning needs
Sufficient—instructional supports usually used in ways matched to student learning needs
Insufficient—instructional supports usually not used in ways matched to student learning needs
Poor—instructional supports always used in ways not matched to student learning needs

Sources
Supplemented—used instructional supports included in materials plus others
Matched—used only instructional supports included in the materials
Replaced—used only instructional supports not included in materials

Findings

Data analysis indicated teachers were fairly consistent in their enactments. Two teachers' enactments tended to be a good match for the intended enactment (Group 1), whereas the other two teachers' enactments were less reflective of the intended enactment (Group 2). To illustrate enactment differences by ratings in each category for each teacher, a color-coded table was constructed. Each rating was converted to a number and assigned a shade (see Table 3). Lighter shades indicate enactments that were more consistent with the intended, and darker shades indicate enactments with less consistency. Although each teacher's color pattern is unique, two groups of enactments can be identified.

Table 3
Category ratings represented by color for each teacher

Analysis Category	Ratings	Group 1		Group 2	
		Ms. Franklin	Ms. Wells	Mr. Davis	Ms. Turner
Accuracy	4 = scientific	3	3	3	2
	3 = sufficient				
	2 = semi accurate	3	2	3	2
	1 = nonscientific				
Completeness	4 = thorough	3	3	1	1
	3 = sufficient				
	2 = incomplete	4	3	1	1
	1 = insufficient				
Opportunities	4 = maximum	4	4	2	2
	3 = sufficient				
	2 = insufficient	4	4	2	2
	1 = minimal				
Similarity	4 = high	4	4	2	2
	3 = medium				
	2 = low	4	4	2	1
	1 = none				
Adaptation	4 = high	3	2	2	1
	3 = none				
	2 = medium	3	2	2	1
	1 = low				
Instructional supports	4 = high	3	4	2	1
	3 = medium				
	2 = low	3	4	2	1
	1 = none				
Appropriateness	4 = excellent	3	4	2	2
	3 = sufficient				
	2 = insufficient	3	3	2	1
	1 = poor				

Each category is represented by two ratings to represent enactments variation. When ratings did not vary, the category was assigned the same code each time. The category "Sources" contains only three rating levels and is not included.

[a] Completeness category of excessive content was not included here, however; excessive content coverage was observed with insufficient content coverage.

[b] Adaptation rating of "none" is ranked as a 3 to represent no adaptations higher than adaptations that do not address student learning needs.

Overview of Enactments

Group 1 enactments were generally rated high across all categories (Table 4). These teachers included many opportunities for student learning and offered many instructional supports that were appropriate. Enactments were rated high for completeness and similarity, and the supports from the materials were used even when supplemented. Group 2 enactments were generally rated medium or low in each category. Teachers included some opportunities for student learning and offered some instructional support, but these were not always appropriate. Enactments were rated low for completeness and similarity. Some instructional supports from the materials were used but often these were replaced with the teacher's supports. Only accuracy was not a unique indicator. Teachers who presented science accurately were in both groups.

Enactment Group 1 teachers tended to spend more time on tasks, particularly during discussions and small-group work (Table 5). Also, during small-group work, students were allowed

Table 4

Ratings for each analysis category summarized across lesson sequences and teachers with supporting evidence from enactment for Group 1 and Group 2

Group 1 Enactments: More Consistent with Intent	Group 2 Enactments: Less Consistent with Intent
Accuracy: Varied *sufficient* with some *semiaccurate*	**Accuracy:** Varied *sufficient* or *semiaccurate*
Explicit statements	Explicit statements
• Definitions were accurate	• Definitions were accurate
• Explanations were accurate; minor inaccuracies were few	• Explanations were accurate or inaccurate—*varied*
• Examples were accurate	• Examples were not used or were often inaccurate—*varied*
Guidance	Guidance
• Directed student attention to the important aspects of demonstrations or tasks, led students to the appropriate ideas	• Directed student attention to tasks to be completed or irrelevant factors
• Sometimes guided students to write appropriate form of hypothesis, predictions, and conclusions—*varied*	• Little guidance in connection with predictions or hypothesis or guided students to inappropriate form—*varied*
• Sometimes guided students to incomplete investigation design—*varied*	• Little guidance in connection with investigation design or guided students to inappropriate design
Response to students	Response to students
• Accurate and inaccurate student statements distinguished; inaccurate redirected, accurate acknowledged	• Accurate and inaccurate student statements distinguished; inaccurate redirected, accurate acknowledged or not distinguished—*varied*
• Inaccurate student statements generally not corrected during presentations	• Inaccurate student statements not addressed during student presentations
Completeness: *sufficient*	**Completeness:** *insufficient*
• Concepts intended for the lesson sequence are addressed	• Concepts intended for the lesson sequence are not addressed or are only defined
• Process ideas regarding variables and design are sometimes addressed—*varied*	• Process ideas regarding variables and design not addressed or are only defined
• Graph ideas are addressed	• Graph ideas are addressed sometimes as definition or identification—*varied*
• General statements sometimes addressed—*varied*	• General statements not addressed
• Connections between ideas not explicit or not made—*varied*	• Connections between ideas not made
• Did not add content beyond that intended	• Added content beyond that intended
Opportunities: *Maximum*	**Opportunities:** *Insufficient*
Time	Time
• Time was adequate in class for each type of activity	• Time was short for all activities except final student presentations
Type of activity	Type of activity
• Actions were completed	• Actions were completed
• Small-group work was frequent and included action and thoughtful work	• Small-group work was limited
• Discussion were frequent and used student ideas	• Discussion was limited
Structure	Structure
• Activities sequenced and cycled	• Activities clustered by type
• Small-group work was monitored but not overly structured, students allowed to discuss and work together	• Small-group work was monitored closely for completion

Table 4
(Continued)

Group 1 Enactments: More Consistent with Intent	Group 2 Enactments: Less Consistent with Intent
• Discussion used student ideas and either clearly focused and directed or followed student ideas	• Discussion presented teacher ideas and explanations
• Investigation structured by question or loosely structured by question—*varied*	• Investigation structured by list of items to complete or not structured—*varied*
Similarity: *High*	**Similarity:** Varied *medium* to *low*
• Major learning opportunities matched	• Major learning opportunities matched or some changed—*varied*
• Phases of opportunities matched	• Phases of opportunities some matched some changed
• Sequence of opportunities matched	• Sequence of opportunities matched or sometimes changed—*varied*
• Sequence of phases matched	• Sequence of phases often changed combined like activities
• Emphasis often matched occasionally modified	• Emphasis often changed
Adaptation: Varied *none* to *medium*	**Adaptation:** Varied *medium* to *low*
• Did not adapt or added group presentations, added variable to investigation, added more graphing motions as a whole class activity, added demonstrations and questions to final presentation—v*aried*	• Added group presentations, teacher-led activities changed to student activities, small-group activities changed to individual work or added non–content-supporting features, small-group activities changed to individual work—*varied*
Instructional supports: Varied *high* to *medium*	**Instructional supports:** *Low*
Types	Types
• Questions often used to guide students to important content ideas	• Questions used to elicit definitions or sometimes explanations—*varied*
• Hints and reminders used to focus attention on content related aspects of activity and to guide doing a task	• Hints and reminder used as lists of items to complete
• Real life examples and connections to driving question often used	• Real-life examples and connections to driving question rarely used or occasionally used—*varied*
Activities	Activities
• Whole class set-up and discussion many supports	• Whole class set-up and discussion few supports early, less later, several tasks were student self-guided work
• Small-group work fewer supports	• Small-group work frequent prompts
• Presentations have few supports or some questions to support—*varied*	• Presentations have few supports
Appropriateness: *Excellent* to *sufficient*	**Appropriateness:** *Insufficient* to *poor*
• Questions and prompts guided students to focus on appropriate ideas	• Questions and prompts were answered or explained by the teacher or guided student to definitions or voting on right answers
• Hints and reminders addressed ideas with which students may have trouble	• Hints and reminders addressed task completion
• Students ideas requested and sometimes connected to previously stated students' ideas	• Student ideas not requested
• Feedback directed students to appropriate ideas	• Feedback identified mistakes or wrong answers
• Student questions and difficulties were addressed	• Student questions and difficulties were not always addressed or were not addressed—*varied*

(*Continued*)

Table 4
(Continued)

Group 1 Enactments: More Consistent with Intent	Group 2 Enactments: Less Consistent with Intent
Sources: *Supplemented*	**Sources:** Varied *matched* or *replaced*
• From materials used questions to guide discussion, driving question, monitored groups, compared to similar previous activities, monitored groups	• From materials used questions, rubrics, guidelines, monitored groups, or investigation procedure—*varied*
• Teacher added many real-life examples	• Many suggested supports were not used
• Trend matched early, but quickly supplemented	• Teacher added none or added examples, prompts for task completion and definitions—*varied*
• Added supports from earlier parts of the materials to later lesson sequences	• Trend matched throughout or matched early then quickly replaced—*varied*

Table 5
Characteristics of enactment for Group 1 and Group 2

Enactment Group 1	Enactment Group 2
Types of activities	
Time	Time
• Class time spent on all types of activities	• Class time spent mainly on student actions or teacher presentation activities
• More time spent on small-group work	• More time for whole-class work
• Tasks completed separately and in sequence	• Task sequence rearranged and condensed
• Amount of time associated with completeness	• Amount of time associated with incompleteness
Small-group work	Small-group work
• Both active and thoughtful tasks	• Mostly active tasks
• Few teacher interventions	• Many teacher interventions
• Scaffolds for thinking	• Prompts for completion and correctness
Discussions	Discussions
• Small-group tasks (planning, explanations) given lots of time	• Small-group tasks (planning, explanations) given as individual work or homework
• Whole-class discussions often aimed at concepts	• Whole class discussions often aimed at correct answers
• Student ideas shared	• Teacher presents ideas
• Many instructional supports	• Few instructional supports
Changes over time	
Improved	Not improved
• Opportunities remained high or slightly increased	• Opportunities remained low or slightly decreased
• Supports slightly more appropriate	• Supports less appropriate and less accurate
• Adaptations improved	• Adaptations worsened
Moved away from materials	Moved away from materials
• Adaptations increase	• Adaptations increase
• More instructional support of their own—examples	• More instructional support of their own—completion prompts, examples
• Continued to use suggested instructional supports	• Discontinued use of suggested instructional supports
• Continued to use instructional supports from early portions of the unit	• Did not use instructional supports from early portion of the unit

to discuss ideas and work together with minimal prompting for completion. Prompts and other instructional supports tended to be content understanding oriented, with teachers often asking for student ideas. All phases of student tasks were completed separately, generally in sequence. They provided students opportunities to use technology tools, design investigations, and discuss ideas. However, enactment ratings were less reflective of curriculum intent when challenges were greatest, such as when teachers attempted to present challenging science ideas, respond to students' ideas, structure investigations, guide small-group discussions, or make adaptations. Moreover, enactment ratings were less consistent in parts of lessons where materials did not include lesson-specific educative supports for teachers. Although this group was not necessarily more accurate, the time devoted to tasks of all types allowed students to bring out and develop their ideas and was related to completeness of content presented. Adaptations increased and improved over time. Supports suggested in the materials were used early in the unit. Later, other supports, in addition to those suggested in the materials, were usually appropriate and accurate.

Group 2 teachers tended to spend less time on tasks, particularly during discussions and small-group work. During small-group work students were limited in their conversations; they were prompted to complete their work or were instructed to work individually. Tasks of a similar type were often condensed into one session rather than cycled and repeated over time. Explanation phases and other writing-based tasks frequently were assigned as homework rather than as tasks for small-group collaboration. Questions tended to guide students to definitions or toward what was stated as the right answer rather than exploring ideas. Although this group was not necessarily less accurate, the lack of time devoted to tasks of all types did not allow students to present and develop their ideas and was related to insufficient completeness of content presented. Adaptations increased and tended to be insufficient or poor. Supports suggested in the materials were used early in the unit. Later, other supports not suggested were used. These replacements were often less appropriate or inaccurate.

To illustrate the range of enactments just summarized, in the following sections we expand our descriptions and provide examples from teachers' enactments. The examples are primarily from Group 1 enactments because these enactments were more reflective of the intended enactments and therefore have a greater potential to inform efforts to promote reforms.

Accuracy. The accuracy of science ideas presented in Group 1 enactments as explicit statements, such as definitions, explanations, or examples, was generally appropriate, with minor errors. For instance, both Ms. Wells and Ms. Franklin accurately explained the motion of a small cart by stating that students needed to apply a force to the cart to start it and another to stop it, but then later described the cart at rest as having no force acting on it rather than more accurately stating there were no unbalanced forces acting on the cart. Variation in accuracy, however, was seen when content ideas were more complex and in connection with students' content statements. In the changing motion detector lesson sequence, for example, Ms. Wells had difficulty leading students to an accurate explanation of the apparent motion of a plumb bob (a washer on the end of a string) held while standing and then quickly walking forward or turning. Based on students' attempts to explain their observations, Ms. Wells led students to believe the apparent motion was due to wind or gravity rather than the continued state of motion of the plumb bob. Ms. Franklin, on the other hand, was able to guide students to explain that, when a student started walking, the plumb bob remained in place until the string pulled it forward.

Student presentations were often a source of inaccurate statements—made by students, not teachers. When the teacher did not address those ideas, however, the inaccurate statement became part of the science content that was presented. For example, in Ms. Franklin's class, one student group made a variety of accurate and inaccurate statements during the course of their presentation as they described the event of an egg and cart rolling the down a ramp and resulting in a broken egg.

Students made accurate statements, such as ‘‘When the egg moved down the ramp gravity was acting on it,’’ and inaccurate statements such as “The egg’s velocity and acceleration rose as it traveled down the ramp.” Ms. Franklin did not comment during or after any of these statements. Ms. Wells did ask students questions during their presentations to the class and was quite persistent in following up on their ideas, but she did not always address the accuracy of students’ ideas. For example, Ms. Wells asked one student group a series of questions to help them identify increasing velocity on their velocity–time graph. She asked ‘‘Where is the increase?’’ ‘‘Is the increase on this section of the graph?’’ ‘‘How is this graph the same as the last graph we saw?’’ and ‘‘Did the speed increase?’’ These were answered without accurate responses from the student presenters. Ms. Wells also asked this group to explain what they meant by ‘‘collected speed’’ and the group accurately described the cart as accelerating. Through her questions, students were prompted to make more complete presentations. Sometimes this drew out accurate ideas. However, often the class was left without accurate presentation of ideas, such as the explanation of the motion graph.

Completeness. Teachers in Group 1 were generally very complete in presenting the intended science ideas. Group 1 teachers devoted considerable time to each type of activity and students were encouraged to bring out their ideas. However, when enactments were rated less than complete, the intended science ideas that were missing were often complex ideas, such as general statements or connections to other ideas. For example, when exploring change in velocity, Ms. Wells did not make the generalization that a change in velocity is a change in speed or direction. She also did not make explicit connections between distance, time, and direction of a student’s motion to the distance, time, and direction indicated by a distance–time graph illustrating this motion. In contrast, Group 2 teachers tended to be incomplete in presenting the intended science ideas while including other ideas traditionally associated with force and motion but not intended by this unit. For example, Mr. Davis explained how to use position–time graphs to calculate velocity and emphasized solving equations such as $v = d/t$, but did not support students in interpreting the motion represented by the graph.

Process ideas related to investigation design also were often presented incompletely. For example, in one investigation students were to let a cart roll down a ramp and strike a wooden block at the bottom. They were to observe the distance moved by a block as the mass in the cart was increased. In this investigation, Ms. Wells encouraged her students to ‘‘try some things.’’ She listed a variety of variables and reminded students to first make a prediction, but did not connect variables to the investigation question nor did she describe them as independent, dependent, or control. Rather, she told the class to “Try the cart with no mass, just the egg. Then try some different variables. You can lower your height, increase your height [of the ramp], add two barriers, add mass to the cart.’’ Ms. Wells reminded students to record their observations. She even summarized the directions, ‘‘Start with the egg and cart, then change some variables. Let me know what the variables you change are.’’ But she did not give students any guidance for how to select or control variables in an investigation.

Opportunities. In Group 1 enactments, opportunities for students to do and think were abundant. Both Ms. Franklin and Ms. Wells gave students ample time to complete each type of activity, time to work in groups, and time to share ideas in class. These enactments included the use of technology, student investigations, and discussions, all with ample time to work with science ideas. In particular, students were repeatedly given opportunities to learn with technology within a lesson sequence. For example, using predict–observe–explain (POE) cycles, students created computer-generated graphs for three motions in one direction, and then returned to the computers to generate graphs for three more motions in the opposite direction, and returned again to generate graphs for motions that involved both directions in sequence. When students determined that a motion needed to be repeated, they moved to the computers to do so. Students also had ample opportunity to plan and design investigations. For example, students were given time to chose variables, plan their procedures, and decide what data they would collect. Students also worked together to analyze their data and make conclusions that they shared with the class.

Similarity. Both teachers in Group 1 were highly consistent with the intent of the materials. Opportunities described in the materials were observed in enactments in a similar sequence with approximately the same emphasis. For example, when Ms. Franklin and Ms. Wells presented Newton's first law, each of the demonstrations was presented in the suggested sequence, the POE cycle was completed for each demonstration, and each intended facet of Newton's first law was explored. In particular, the explanation phase of activities was included at the suggested intervals. For example, Ms. Franklin had her students stop for explanations after each type of motion, consistent with a POE cycle. Teachers in Group 2, on the other hand, tended to rearrange and condense activities by type. For example, rather than repeating the POE cycle, all demonstrations were conducted in quick succession for students to observe. Predictions were mentioned briefly or omitted and all explanations were assigned as homework.

Adaptations. Ms. Franklin rarely included an adaptation, whereas Ms. Wells adapted the lessons a bit more frequently. When adaptations were observed in Group 1 enactments they were mainly additions to the intended student activities rather than replacements. For example, in the ballistic cart demonstration lesson sequence, Ms. Wells adapted the lesson by including student presentations at the end of the series of demonstrations. This was to be their quiz. Student groups were each assigned a question related to the main ideas addressed so far. One group was given the questions ‘‘Explain what caused the ball to pop out?’’ ‘‘Was the ball initially going at the same speed as the cart?’’ ‘‘What made the ball go back in the cart, and how does it tie in with Newton's first law?’’ This adaptation did address the intended student learning goals and student presentations were recommended in the unit as a form of assessment. However, each group addressed only one idea and class participation was limited.

The adaptations were not always student presentations. Ms. Wells also included an uncooked egg in the ramp-and-cart investigation; included more motions during the graphing lesson sequence; and included demonstrations of helmet testing during the helmet presentations, so that students could prove their claims about helmets. Adaptations did improve over time. Whereas the first student presentations were simple reporting of answers and the uncooked egg complicated the first investigation, later adaptations were more appropriate. Additional motion-graphing experience was needed to help students connect motion to graphs and including demonstrations of their helmet tests made design issues evident. Group 2 adaptations were more frequent but less likely to address students' learning needs. For example, Ms. Turner embellished student presentations with songs and logos that did not address science ideas.

Instructional supports. Many instructional supports were included in Group 1 enactments. Ms. Franklin and Ms. Wells both used many real-life examples and connected ideas to the driving questions or other lessons. They offered more supports during whole-class discussion. Small-group work was an opportunity for students to work through tasks—both active and thoughtful—on their own. Both teachers monitored group work and were interactive as needed. The supports in Group 1 enactments tended to be of the type to guide students to consider science ideas as well as help students to organize and carry out tasks. For example, Ms. Franklin reminded students to think about what each axis of the motion graph indicated and to think about how far they might travel in the classroom when moving slowly versus more quickly. Whereas Group 1 teachers used prompts and questions to guide student thinking, Group 2 teachers used prompts to press students to complete tasks and questions to guide students to the ‘‘right’’ answer.

Appropriateness. The types of supports used by Ms. Franklin and Ms. Wells tended to emphasize ideas and concepts, but Ms. Wells' questions and examples were more responsive to student ideas and Ms. Franklin tended to emphasize accurate and complete content. Although teachers used similar types of instructional supports, such as asking students to give reasons for their prediction or explanation statements throughout, these were not always used in ways that matched students' learning needs. For example, asking students why they thought the ball would land behind the moving ballistic cart brought out student ideas about the motion of the ball. However, asking students the same ''give me the reason why'' question in connection to why the washer on the string moved did not help students identify similarities between instances when motion was changing and when motion was not changing as indicated by the position of the washer.

Sources. Teachers in Group 1 used most of the supports suggested in the materials and, over time, supplemented these with their own examples and questions. Ms. Wells tended to add more of her own instructional supports and included them somewhat earlier. The teacher-added supports tended to be examples and questions to guide students to the desired science understanding. For example, Ms. Wells described continued motion and friction using an example of driving a car and using the accelerator to keep moving. She also pressed students to explain their motion graphs by asking specific questions in response to student statements. In addition, teachers' use of certain types of instructional supports suggested for early lesson sequences persisted even though these were not suggested again in later lessons. For example, Ms. Wells continued to ask students ''How is this related to the driving question?'' and ''What is the reason for your answer?'' even when these questions were not suggested in the specific lesson or, in some cases, not the best type of question for the lesson as described under the category of appropriateness. Ms. Franklin also continued to use specific instructional supports in later lessons, but in a more appropriate manner. For example, in the helmet testing and presentation lesson sequence near the end of the unit, the materials offered little description of how to help students design their investigation. Ms. Franklin used the same questions from an earlier investigation to support students in choosing variables based on what they were testing in this investigation.

Discussion

Accuracy

Science ideas were generally presented accurately in Group 1 enactments. It was notable that teachers' examples and connections to the contextualizing features of the unit, such as the driving question, presented appropriate and accurate science ideas. However, for more challenging content ideas, accuracy was more variable. Teachers' limited content knowledge would be an explanation. When comparing teachers' lessons before and after a summer program that focused on content knowledge and conceptual change teaching, Smith and Neale (1989) found that improving elementary teachers' level of content knowledge also improved the accuracy of ideas presented to students. At the high school level, Hashweh (1987) found that teachers' low subject matter knowledge in biology and physics resulted in inaccurate explanatory representations of content, such as examples and analogies, as well as difficulties in responding accurately to students' statements. We did not examine teachers' content knowledge, but there is no evidence to suggest these teachers were better prepared than most in physics content.

Accuracy also was problematic when Group 1 teachers were responding to or guiding student thinking during class discussions and student presentations. When students expressed alternative ideas in class, teachers tended not to comment on the accuracy of these ideas. Others investigators also reported that teachers, in spite of fairly good content preparation, are reluctant to interfere with student presentations or with students exploring their own ideas in science classrooms

(Krajcik, Blumenfeld, Marx, Bass, & Fredricks, 1998; Smith & Neale, 1989). In this case, teachers may have thought discussions were meant to be motivating or may have considered student presentations to be performances (Blumenfeld et al., 1991). Teachers also may have been unclear as to what types of feedback were appropriate in these circumstances.

Completeness

Teachers in Group 1 addressed nearly all the intended ideas, presented ideas in the intended sequence, and tended not to include additional ideas beyond the level intended. This description contradicts reports that teachers use texts for large topic selection and then select, omit, rearrange, and supplement topics within this larger topic framework (Bybee & DeBoer, 1994). This is what we found in Group 2 enactments. Moreover, the supplemented topics tended to be equations and terms likely to have been presented in traditional approaches to force and motion. Hashweh (1987) and Smith and Neale (1989) also reported that teachers continue to include concepts from prior teaching experiences, particularly when teachers' content knowledge is weak. In light of these reports, it is noteworthy that teachers in Group 1 enactments did address nearly all of the intended science ideas in sequence without supplementing topics.

Completeness, however, was quite variable in Group 1 for process ideas related to investigations. For example, teachers did not necessarily discuss variables in connection with the investigation question or as a guide for investigation design. Rather, in one instance, students were given ideas for what they could do or try, essentially increasing the number of variables for students to consider. One reason may be that doing inquiry is thought to be motivating for students (Blumenfeld et al., 1991). Investigations may be viewed as opportunities for students to manipulate things and talk in small groups (Hofstein & Lunetta, 1982). Teachers may overlook recommendations for students to learn *about* inquiry as well as through inquiry (National Research Council, 1996). Another explanation may be the complexity of explicitly addressing both concepts and process ideas simultaneously. Enactments often demonstrated teachers addressing concepts and process ideas in different portions of the lesson sequence.

Opportunities

Opportunities in Group 1 enactments included the repeated use of technology, planning and designing investigations, and thoughtful discussions, all with ample time to work with science ideas. This finding is important because we have evidence that teachers are typically challenged by innovative curriculum and new instructional practices associated with educational reform (Tschannen-Moran, Hoy, & Hoy, 1998). Specifically, during initial attempts to enact inquiry-based science, teachers are challenged by the use of new strategies and technology to support student learning (Marx et al., 1997). Indeed, teachers in Group 2 demonstrated some of these challenges when they limited students' experiences with technology and demonstrated difficulty in using the POE strategy in an effective manner.

Teachers in Group 1 enactments also gave students opportunities to plan and design investigations. For example, students were given time to choose variables, plan their procedures, and decide what data they would collect. Students also worked together to analyze their data and make conclusions that they shared with the class. The fact students participated in investigation design, beyond completing the actions of an investigation, is noteworthy in light of many reports that investigations are often proceduralized and emphasis is placed on actions students will complete (Hofstein & Lunetta, 1982).

Of particular interest is that teachers in Group 1 gave students opportunities to discuss ideas, both in small groups and as a whole class. Small-group work was used for thoughtful tasks such as planning and explaining. Whole-class discussions were opportunities for students to contribute their own ideas. For a variety of reasons, this is not always the case. First, supporting collaboration is difficult and challenges teachers' abilities to manage and guide students (Marx et al., 1994). Second, because of concerns about covering required content ideas, teachers may be hesitant to let students participate in planning and designing investigations (Ladewski, Krajcik, & Harvey, 1994). Finally, teachers may consider small-group work to have only motivational value because students have the chance to talk and to ''do'' activities, and therefore may not include many such opportunities (Blumenfeld et al., 1991; Hofstein & Lunetta, 1982).

Finally, in Group 1 enactments, student ideas were asked for and used in discussions, giving students many opportunities to bring up ideas with which teachers may not have been comfortable or to which they were unable to respond. In a careful examination of classroom conversations, Carlsen (1992) found that teachers often steered class conversations away from topics with which they were unfamiliar. Although this study did not measure teachers' content knowledge, inaccuracies in science presentation were observed that might indicate limits in content knowledge. Group 2 enactments demonstrated these aspects when teachers tightly directed whole-class conversations. Guiding students in conversations that develop student's ideas is difficult and can be intimidating. It is encouraging that Group 1 teachers made initial steps in this direction.

Similarity

Group 1 enactments were rated as quite similar to the intended lessons in the materials. Lesson components described in the materials were observed in enactments in a similar sequence with approximately the same emphasis. For example, when Newton's first law was presented, each of the demonstrations was presented in the suggested sequence, the POE cycle was completed for each demonstration, and each intended facet of Newton's first law was explored. This contradicts previous studies reporting that teachers do not use reform-based materials or select individual tasks to include without changing their instructional methods. Putnam and colleagues (1992) described four fifth-grade teachers' attempts to enact reform in mathematics. These teachers loosely followed the textbook designed to align with the state's framework. They selected topics from the textbook, but did not include all of the lessons nor did they stick to the recommended order. In fact, this was observed in Group 2 enactments. Teachers omitted some portions and rearranged others.

Adaptations

Adaptations in Group 1 enactments were infrequent and small scale, but consistent with the types of tasks included in the materials and addressed the intended science ideas. For example, teachers added more explicit directions for planning the final investigation and more student group presentations. This finding indicates teachers considered recommended practices when modifying student tasks. This is of interest in light of previous research indicating teachers either used curriculum components or did not, without a description of the nature of the changes (Bybee & DeBoer, 1994).

The adaptations, however, were not always appropriate for students' learning needs. For instance, including additional variables in the first student investigation complicated the design process before students had the opportunity to plan more straightforward investigations. This type of difficulty should not be surprising given the level of skill required to judge students' thinking and plan accordingly (Borko & Shavelson, 1990). In fact, adaptations improved as teachers gained experience through enactment. For example, in a later investigation, this same teacher included discussion of investigation design as part of students' presentations. This supports the theory that enactment is an important component of professional development (Marx et al., 1998).

Instructional Supports

Instructional supports were offered frequently in Group 1 enactments. Supports tended to guide students to consider science ideas as well as help students to organize and carry out tasks. Teachers also included many real-life examples and references to the driving question. This finding is encouraging in light of reports that support of student thinking is one of the more challenging aspects of enacting inquiry. In inquiry-based science, teachers struggled to learn how to use driving questions, guided students in mastering lower level ideas and facts, and felt the need to direct lessons to ensure students received the right information (Ladewski et al., 1994; Marx et al., 1994). By contrast, Group 2 enactments showed teachers prompting students for definitions and for completion of active tasks. Rarely did these teachers refer to the driving question. This is consistent with Meyer's (1997) explanation that teachers use low-level questions to prompt students to recall information because they believe students demonstrate understanding by recalling facts and need only to be physically active in order to learn.

Instructional supports in Group 1 enactments were offered less frequently during small-group work. This practice allowed students opportunities to discuss ideas uninterrupted by prompts for completion as seen in Group 2. However, this also left students without teacher support for thinking. This challenge has also been observed in other studies of inquiry-based science. In attempts to give students opportunities to collaborate, teachers gave students too much responsibility and not enough guidance (Marx et al., 1994; Scott, 1994). Again, this indicates the difficulty of supporting student thinking.

Appropriateness

The appropriateness of instructional supports observed in Group 1 enactments was generally sufficient, but was more variable when the materials offered less PCK support. Although teachers used similar types of instructional supports, such as asking students to give reasons for their prediction or explanation statements throughout, these were not always used in ways that matched students' learning needs. For example, asking students why they thought the ball would land behind the moving ballistic cart brought out student ideas about the motion of the ball. However, asking students the same "give me the reason why" question did not help students identify a pattern in their data. The first example occurred in an early lesson sequence wherein the materials included abundant support for teacher thinking. The second example occurred in a later lesson sequence with little teacher thinking support. This finding supports the premise that knowledge about student thinking in specific topics and lessons—PCK—is essential for skilled teaching (Gess-Newsome & Lederman, 1999; Shulman, 1986). In this case, simply knowing to ask students to justify their ideas to help them to think through their reasoning was not sufficient. Teachers also needed to understand students' thinking about specific ideas and how they view the idea in relation to specific tasks. Indeed, when educative features to support PCK were abundant, teachers demonstrated appropriate support for students.

Sources

In Group 1 enactments teachers used instructional supports from the materials throughout the enactment. Over time, they also included supports of their own. The teacher-added supports tended to be examples and questions to guide students to the desired science understanding. In addition, teachers' use of certain types of instructional supports suggested for early lesson sequences persisted in spite of the fact that these were not suggested again in later lessons. This finding contradicts indications that teachers tend to focus lessons on procedures. In the same set of math studies, the focus of lessons was modified from conceptual problem-solving to learning computational procedures (Heaton, 1992; Putnam et al., 1992). This also occurred in Group 2 enactments. These teachers used their own supports to focus students on procedures. Because teachers in Group 1 used supports consistent with those suggested in the materials, lessons retained a focus on understanding rather than procedures.

Materials in Reform

In Group 1 enactments, teachers purposefully and consistently used the materials to guide their enactments. Their enactments illustrate initial attempts at reform that are encouraging. One explanation is that these teachers were also supported by the systemic reform effort (Blumenfeld et al., 2000). The systemic reform effort did remove some known barriers to enactment. Teachers had access to computers and other necessary equipment, had the support of the administration, and were assured the materials were consistent with district goals. Yet, this alone does not explain how teachers were able to take positive steps toward guiding student inquiry, supporting collaboration, and incorporating learning technologies in their classrooms. Another explanation is that the professional development worksessions helped teachers learn how to enact inquiry science (Fishman & Best, 2000). The worksesssions were essential. During these sessions, teachers were introduced to project-based science, technology tools, and this curriculum unit. However, not all of the specific tasks, discussions, or science ideas included in the lesson sequences examined in this study were discussed or practiced. Moreover, teachers did not practice these lessons with students. In addition, variation in enactments corresponded with variation in the support for teacher thinking in the materials. A better explanation is that a combination of factors, including the support for teacher thinking provided in the materials, contributed to the observed enactments.

In spite of encouraging first attempts at reform, Group 1 enactments demonstrate still how difficult it is to enact an innovative curriculum. In particular, enactments showed how difficult it is to ensure students are given opportunities to explore their own ideas through inquiry while ensuring that students are given adequate support to guide their thinking. Teachers will need support beyond what can be supplied through curriculum materials. However, classroom enactment is considered an essential phase of learning about teaching. For example, Marx, Freeman, and Krajcik (1998) recommended cycles of Collaboration, Enactment, Reflection, and Adaptation (CERA). This means enactments need to give teachers important classroom experiences on which to reflect and build their own understanding of teaching. It is reasonable to assume that teachers, even when supported by exemplary materials, would demonstrate difficulties when making initial attempts to enact inquiry-based science instruction. However, when materials enable teachers to take the first steps in the direction of reform, enactment can be an important learning opportunity for teachers.

Enactments in Group 2, on the other hand, did not demonstrate the same encouraging first steps. For whatever reason, these teachers were not able to use the materials in the same purposeful way to guide their enactments. This does not mean that these teachers did not try to use the materials. In fact, both Mr. Davis and Ms. Turner said they followed the lessons in the materials. Although Ms. Turner reported following the lessons from the student materials midway through the unit, Mr. Davis used the teacher materials throughout. In addition, the fact that Ms. Turner's enactment ratings declined after she discontinued using the teacher materials supports the premise that these materials were helpful. Perhaps the support of the systemic reform effort was not sufficient for these teachers. These teachers were not supported in exploring new instructional methods as described by the materials. For instance, one teacher was required to continue covering the regular objectives in addition to those identified in the new materials. Both teachers expressed concern with covering additional objectives and did not have flexible and reliable access to computers. When the context did not actively interfere, Group 1 teachers were able to begin exploring new ways to teach. School administrators also need support in understanding new instructional practices and how to support teachers in these changes (Blumenfeld et al., 2000).

Group 2 enactments also demonstrate that we cannot assume all teachers will be able to purposefully and consistently use materials to guide their enactments. It is possible that the support in the materials did not meet the needs of these teachers. Not all teachers benefit from resources designed to support their learning (Collopy, 1999; Krajcik et al., 1996; Meyer, 1997). For example, in a study examining teachers' use of and learning from elementary mathematics materials designed to be educative for teachers, Collopy (1999) reported that one of the two teachers was not able to use the materials as intended. For teachers in enactment Group 2, other types of professional development may be able to offer the support they need.

Conclusions

Overall, our findings suggest that using materials in a careful way can assist teachers in enactment of reform-based instruction. Moreover, it appears that materials are most beneficial for teachers when the lesson descriptions are quite detailed and the supports for teacher thinking are lesson-specific and consistent throughout. The enactment descriptions provided here indicate areas where developers should pay particular attention to the challenges for teachers attempting reform. Findings also indicate that materials alone are not sufficient. Professional development is essential to help teachers plan for and reflect on classroom enactments. This support should include how to use and learn from reform materials designed to support teacher thinking. Reform efforts also must include efforts to create systemic change in context and policy to support teacher learning and classroom enactment.

The importance of this study lies in its ability to inform efforts to create innovations that teachers can use to learn and enact new practices. Cohen, Raudenbush, and Ball (2002) argued that instructional improvement depends on "improving students', teachers', and school leaders' use of resources, improving knowledge and skill in using resources for instruction, improving resources' usability, and enhancing conditions which enable resource use" (p. 86). This means that creating innovative science materials is not enough. Teachers need materials they can use to create inquiry environments with their students as well as support in learning how to use the materials and school contexts that enable them to do so. Only by understanding teachers' initial attempts at reform and the range of enactments that are reasonable to expect can we begin to develop materials that support a variety of teachers in making changes.

The present investigation has only begun to address this issue. Our study has examined teachers' interactions with students as they attempt to use reform materials to enact inquiry science; however, descriptions were based on initial attempts of only four teachers, of which only two were able to purposefully and consistently use the materials to guide their enactment. Moreover, this study did not explicitly measure teachers' learning or connect aspects of teachers' enactments to specific features of the materials. Thus, interpretations should be considered as initial indicators for areas for further development and study. The materials used in this study, although pilot-tested in classrooms prior to this research, can be further improved based on these findings. Research that examines classroom enactment by increased numbers of teachers supported by the improved materials should follow. Through this work, materials that are appropriate for larger scale studies could be created.

The findings in this study demonstrate that teachers' thinking cannot be overlooked if we are to develop innovations that will impact student learning. Understanding how teachers enact reforms is critical to creating materials that will support teachers in their initial attempts. Although materials are generally considered an essential component of the curriculum reform process, designing materials to explicitly support teachers in learning and enacting new instructional practices is a new idea. Research to ensure the development of quality materials that teachers can use is essential. After funding for intense professional development associated with reform efforts is complete, the materials will remain. Moreover, in large-scale reform, where it is important to address national and local content standards and inquiry, it is not likely that teachers will be able to create their own curriculum. Materials have become an important resource to guide and support teachers in enactments (Cohen et al., 2002). By creating materials that are well matched to teachers' learning and support needs we can begin to promote real instructional improvement.

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