Supporting Science Teacher Thinking Through Curriculum Materials

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Abstract: Teachers need high quality materials to support their work with students and promote teacher learning from classrooms beyond what would normally be the case. Such teacher educative materials would be designed to explicitly enhance teacher thinking in relationship to students and science in classroom contexts. Designing materials specifically for teacher learning, however, is an intriguing yet largely untested idea. In this study, one 7th grade teacher used five inquiry science units with varying amounts and types of educative features over a two year period. Written pre and post lesson teacher reflections, informal interviews, and daily classroom videotape were collected. Analysis focused on aspects of inquiry teaching that are challenging for teachers to learn and illustrate pedagogical content knowledge. Comparisons overtime and between lessons with different types and amounts of educative support in the materials were made. Analysis identified characteristics of materials that guide teacher thinking and support inquiry science teaching.

Introduction

Teaching excellence can have a substantial impact on student learning (Darling-Hammond, 1999). To ensure excellence, however, teachers need high quality materials to support their work with students and promote teacher learning from classrooms beyond what would normally be the case (Cohen *et al.*, 2002; Putnam & Borko, 2000). To address the concerns of reformers in science, teachers need continuing support to develop skill in guiding student inquiry (e.g. designing investigations and developing explanations), supporting collaboration, and incorporating learning technologies in ways that engage all students in actively constructing deep understanding of important science concepts (NRC, 1996). One promising new idea is to include explicit support for teachers to learn about teaching within curriculum materials making them educative for teachers (Davis & Krajcik, 2005; Schneider *et al.*, 2002). Such educative materials would be designed to explicitly enhance teacher thinking in relationship to students and science in classroom contexts. What is needed, however, are specific design ideas based on classroom research to guide developers in creating teacher educative materials. The goal of this study was to identify characteristics of materials intended for teacher use that guide teacher thinking in ways that encourage excellence in science teaching.

Theoretical Framework

Designing materials to be educative for teachers is a relatively new idea. The idea is to develop materials to explicitly support teacher learning, beyond what would normally be the case, through their use in classrooms. This vision, however, is dependant upon development of specific ideas for design of materials to meet teachers' needs for learning and enactment support. Many possible approaches have not yet been fully explored, however, research on teaching and teacher learning can guide our thinking and research on this innovative approach to supporting teachers in reform-oriented teaching.

Reform-oriented Science Teaching

Reformers interested in improving teaching are encouraging teachers to utilize student-centered instructional practices. In science, inquiry learning environments are recommended to engage students in seeking answers to questions, experiencing phenomena, sharing ideas, and developing explanations of science embedded in the everyday world (NRC, 1996). 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 (Minstrell & Van Zee, 2000). 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. To support meaningful discussions teachers need to help students participate in dialogues that require listening, questioning, and responding among peers and teachers. 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.

Classroom-based Experiences

Research suggests that some of the most powerful and motivating learning opportunities for teachers are grounded in classroom experiences (Putnam & Borko, 2000). One example that supports this claim comes from a study of reform initiatives in California. Only those professional development opportunities that focused on curriculum and students resulted in improved student scores (Corcoran, 1995). Providing access to classrooms, however, is not sufficient to guarantee teachers will develop appropriate knowledge and skills. Teachers need guided opportunities to think about and reflect on students' thinking (Putnam & Borko, 2000; Wilson & Berne, 1999). Moreover, teachers need experiences that are consistent with current ideas about how students learn science. We have evidence to suggest that reform materials with detailed lesson descriptions can help teachers enact inquiry (Schneider *et al.*, 2005). To be educative, however, materials need to engage teachers in thinking about teaching as they offer teachers experiences with students that are consistent with current standards for teaching science.

Pedagogical Content Knowledge

One useful construct to guide our thinking about teacher learning in and out of classrooms is pedagogical content knowledge (PCK). PCK is an amalgamation of content, pedagogy, and context knowledge described as knowledge unique to teaching (Shulman, 1986). For science teachers PCK includes knowledge of science specific strategies, various ways to represent content, and students' thinking about science ideas (Magnusson *et al.*, 1999). Although more evidence is needed we have some evidence to suggest that teachers need to understand science from a pedagogical perspective (i.e. PCK) in order to make the most impact on student learning (Nathan & Petrosino, 2003; Wayne & Youngs, 2003; Wilson et al., 2001). Efforts guided by PCK have been very successful in promoting teacher leaning. For example, Daehler and Shinohara (2001) are creating modules that guide teachers first in exploring a specific concept in depth as a student, then in considering how students think and learning about these ideas. Materials for teachers focused on developing PCK would encourage teachers to think intellectually about teaching and prepare teachers to think about their students and learn from classroom situations.

Educative Design Ideas

Materials designed intentionally to be educative for teachers would have specific features to address teachers' learning needs. Straightforward strategies address teacher knowledge directly through descriptive overviews or written notes to the teacher to explain content and pedagogy as well as specific strategies, representations, and students' ideas. There is evidence that teachers pay attention to features which target PCK specifically such as explanations of how a specific strategy or representation supports student thinking or information on student ideas such as probable prior knowledge, likely responses, appropriate level of understanding, and which concepts are challenging for students (Schneider & Krajcik, 2002). Based on the idea that teachers think about teaching in cases or stories some developers use descriptive scenarios to illustrate how a lesson might be enacted in the classroom, albeit with mixed results (Collopy, 1999). There also is evidence that teachers can learn by observing students as they participate in lessons that make evident student thinking and that materials can highlight these instances as opportunities for teacher learning (Remillard, 2000).

Guided by ideas from research on teaching and teacher learning, ideas about educative design (Davis & Krajcik, 2005), and by my research with educative materials in classrooms (Schneider et al., 2002; Schneider & Krajcik, 2002; Schneider et al., 2005), I propose that educative materials could:

(a) *engage teachers in planning and teaching* by describing and explaining specific strategies and representations to address specific science ideas, predicting student responses, describing links to ideas and events in future lessons, clearly indicating when text is for teachers' learning or to be read to students, and explaining how to use the materials for planning and their own learning;

(b) *develop teachers' pedagogical content knowledge* by suggesting activities that make student thinking visible to teachers, focusing teachers' attention on students' thinking, providing help to interpret students' responses, and offering suggestions for how to guide student thinking; and

(c) *match teachers' learning needs* by considering teachers' prior knowledge and skill, offering consistent educative support embedded in lessons, providing scenarios and questions in the voice of the teacher, and repeating use of specific strategies and supports for students across lessons.

Purpose of the study

Designing materials specifically for teacher learning is an intriguing yet largely untested idea. Research tells us that pedagogical content knowledge (PCK) of accomplished teachers enables them to guide and develop students' thinking. Research does not tell us, however, what features of materials are most helpful in developing teachers' PCK. The purpose of this study is to explore how reform-based science materials can help teachers develop skill in inquiry teaching. Specifically, three questions guided the research: 1) *What does classroom teaching look like when teachers use reform-oriented materials with supports for teacher learning?*, 2) *What do teachers learn about inquiry teaching when using reform-oriented materials with supports for teacher learning?*, and 3) *What types of educative features are most helpful in supporting inquiry teaching and teacher learning?* In this exploratory study, one teacher used five inquiry science units in her 7th grade classroom over two years. The development guidelines for these units did include educative features for teachers. However, these ideas were included in varying degrees for each unit. Variation in inquiry teaching and PCK across these units can help identify the types of educative supports that are most helpful. In order to design educative materials we need a better understanding of the specific supports teachers need while enacting inquiry in their classrooms. Understanding how teachers use educative materials and how these materials influence teaching will enable developers to create materials teachers can use to enact inquiry in ways appropriate for their students' learning needs.

Methods

This study was conducted in a midsized, urban middle school. Students in this school were predominantly white (92%) with 25% of student classified as economically disadvantaged. Pass rates on the statewide achievement test in science were 66%. Ms. Shirley was certified as an elementary teacher with a focus on science and had 5 years teaching experience, all in science. Ms. Shirley enacted five inquiry-based science units with all 5 of her 7th grade science classes over a two year period. She had previously participated in inquiry science professional development not associated with this project. In addition, she attended a ten day summer institute for teachers new to these units between year one and year two. Ms. Shirley was interested in hands-on activities and was comfortable trying new teaching ideas in her classroom but had not taught an extended inquiry unit prior to participating in this study.

Each unit was designed to engage students in science by seeking a solution to an overall question or problem. Materials for teachers included lesson descriptions and varying levels and types of educative support. Ms. Shirley enacted two, eight-week inquiry science units in year one and three units in year two (Table 1). One of the units from year one was repeated in year two. Weekly written pre and post lesson teacher reflections, monthly informal interviews, and daily classroom videotape were collected.

Table 1. Inquiry science units.

Unit 1: year 1*	Unit 2: year 1	Unit 3: year 2	Unit 4: year 2	Unit 5: year 2*
Life science 8 weeks on communicable disease; Investigate where bacteria are found	*Physical science* 8 weeks on force and motion; Investigate velocity with motion sensors	*Life science* 4 weeks on adaptation, observe, explanation; Investigate animal behavior	*Physical science* 8 weeks on global temperature; Investigate factors influencing temperature	*Life science* 8 weeks on communicable disease; Investigate where bacteria are found

*Unit 1 and unit 5 were the same unit. This unit was updated between enactments.

The written materials for lessons intended to orient teachers to the lesson, guide teachers through the lesson and transition teachers to the next lesson were characterized for how they: (a) engaged teachers in planning and teaching, (b) developed teachers' pedagogical content knowledge, and (c) matched teachers' learning needs. Guided by the specific features listed above each lesson was rated for the extent and depth of support in each category (Table 2).

Analysis was focused on aspects of inquiry teaching that are challenging for teachers to learn and require PCK. Specifically, I looked for and coded (a) opportunities for students to ask and refine questions, gather and analyze data and information, make interpretations, draw conclusions, and report findings; (b) guidance for students to explain, justify, critique, and revise ideas; and (c) support for students to listening, questioning, and responding during discussion among peers and teachers. Comparisons of teacher PCK overtime and between lessons with

different types and amounts of educative support in the materials were made. Also, the types of lessons that appeared to be most helpful for teacher learning were identified.

Table 2. Type of teacher educative support characteristic of each unit.

Unit	Engage in plan and teach	Develop PCK	Match teacher learning need
1	Describe active & thought task Responses not listed Few links Some teacher text highlighted	Activities use student ideas Challenging ideas explained Some learning goals up front Suggested discussion question	Few teacher prior ideas addressed Sporadic educative support Some questions teacher voice Strategies vary
2	Explain active & thought tasks Response to questions & tasks Links ideas, events throughout Teacher text highlighted	Activities revise student ideas St. thinking for phenomena, responses, explanations Learning goals throughout How and why to guide attention, discuss, collaborate	Some teacher prior ideas addressed Consistent educative support Questions and scenarios in teacher voice throughout Repeated strategies
3	Describe active & thought task Some responses to tasks Links to future lessons Some teacher text highlighted	Activities build on student ideas Challenging ideas, responses explained, check student ideas Learning goals throughout How to guide attention, collab.	Short lessons, familiar project Consistent educative support Questions in teacher voice Repeated strategies
4	Directions for active tasks Response to questions listed Links in orient section Teacher text content only	Activities elicit student ideas Student misconceptions listed Learning goals up front How to correct responses; many content questions	Long and technical lessons Consistent content support Little text in teacher voice Strategies vary
5	Explain active & thought tasks Responses preferred listed for questions Link to future lessons up front Some teacher text highlighted	Activities use student ideas Some challenging ideas explained Learning goals throughout How to guide attention and ideas, discussion questions	Few teacher prior ideas addressed Consistent educative support Questions in teacher voice Strategies vary

Findings

Inquiry teaching. Ms. Shirley's initial enactments were consistent with the nature of enactments by teachers who purposefully used materials to guide their teaching (Schneider et al., 2005). In year one, Ms. Shirley gave students ample opportunities to explore phenomena, work with peers in groups, and to create artifacts. She also struggled with guiding student thinking during small group work and focusing students on explaining and revising their ideas during whole class discussion. She did, however, ask for students' ideas. Over time, Ms. Shirley improved her ability to guide thoughtful discussions, particularly when materials provided questions and described possible discussion scenarios. Support for thinking in small group work continued to be relatively weak. In year two, Ms. Shirley continued to provide students with ample opportunities but she also began to provide students with more structure to guide their work. She described more phases for investigations, defined the tasks for small group work, and focused students on their own ideas during discussions. She continued, however, to struggle with how to guide students' thinking toward accurate ideas while building from their own ideas, particularly in small groups.

Teacher learning. Ms. Shirley's ideas about inquiry developed over the two year period (Table 3). Initially she attempted to fit the new lessons into her previous teaching framework. In year two she began to think about teaching within a framework consistent with the intent of the materials. Midway through year two she began to question components of the lesson with this new framework. For example, she wondered why the unit did not focus students on the bigger question of the unit more often. As Ms. Shirley gained experience with these inquiry units she demonstrated a need for more detailed or finer grained support. For example, in unit one she needed questions she could use in discussions and to have the basic strategies described. By unit five she was focusing on specific details of strategies. Her attention to students' thinking also developed over time. In year one, she was concerned about what she might say that would impart misconceptions. In year two, she moved from noticing students' experiences, then students' ideas, to finally making plans to support their developing ideas.

Table 3. Summary description of teacher thinking for each unit based on self report and observation.

Unit	Ability to plan and teach	Level of PCK	Teacher learning need
1	Difficult to interpret materials Uses previous teaching framework, strategies Long term planning is hard	Did not know how students would respond or what would happen Focus on actions, fun Excitement evidence of learn	Prior idea: students do not read Needed explicit guidance for tasks; specific questions and strategies to use with students
2	Usually able to interpret materials Trying new strategies Worries about time in lessons	Did not want add misconceptions Noticed students prior experience Surprised students could do tasks Struggle evidence of boredom	Prior idea: students should not struggle with tasks or ideas; Relied on teacher voice text
3	Able to interpret materials Begin to use new framework Time not an issue	Understood goal, intent of task Considers student thinking States students learn faster w inquiry	Prior idea: too much time on a topic is boring for students Needed more specific guidance for investigation
4	Difficult to interpret materials Questioned recommend tasks Unable to plan long term	Noticed student misconception States goals of student groups Added appropriate context	Prior idea: st. have difficulty working in groups, writing Needed strategies to support student conversation or collab.
5	Usually able to interpret materials Begin to plan for process, link ideas, refining new strategies Plan time for lesson, long term	Noticed students needed guidance in group work; goals, decisions for student thinking Surprised at students' interest in reading	Prior idea: students need excitement Needed fewer questions/topics to focus on per lesson; finer grained support for strategies

Educative features. In the materials, scenarios and questions that were intended to be read aloud to students not only illustrated what inquiry might sound like but also scaffolded Ms. Shirley's initial efforts with discussions to introduce and wrap up lessons. Ms. Shirley struggled with predicting time, initially for lessons but particularly with long range planning. Her ability to plan time improved over time and specifically when the materials had shorter more focused lessons. When materials were explicit on how components of a lesson contributed to the overall goals, enactments were more thoughtful. Student activities that did not have a physical product, such as discussion to develop a plan or make a decision, seemed to help Ms. Shirley focus on student ideas over completing tasks. She continued to need specific questions and explicit learning goals for tasks such as discussions.

Discussion

The findings in this study indicate that teachers do use materials to guide their teaching; however, to support their efforts it is necessary to be quite descriptive and focused. When the materials did not describe specific goals, how events would play out, or how students would respond, Ms. Shirley had difficulty guiding her students. Lessons with multiple goals and tasks also were difficult to understand. Findings also demonstrate that teachers, like their students, are not blank slates. As learners, they have ideas from prior professional development, textbooks, and experiences with students. Ms. Shirley often relied on her prior ideas about teaching and students even though those experiences may or may not have been consistent with inquiry. For example, Ms Shirley's idea that students will not read was based on experiences with textbooks. Guiding students in developing science process ideas such as designing an investigation appears to be particularly difficult. Also, teachers new to extended inquiry, like novice teachers, have trouble judging time (Putnam & Borko, 2000). It is particularly difficult to make long range plans that support activities weeks in advance. When Ms. Shirley began to use a new framework for thinking about teaching she was better able to interpret materials and make plans for her students.

This study provides evidence that materials can help teachers learn and enact inquiry. Ms. Shirley's practice improved over time, but specifically when materials provided particular supports. For example, when the materials provided detailed descriptions of student misconceptions partnered with tasks that highlighted these ideas within their own students, Ms. Shirley noticed that her students had misconceptions. This also illustrates how materials can support teachers in learning about teaching by studying their students and their practice. Consistent with the construct of PCK, it appears to be necessary to for teachers to integrate ideas about teaching science with an understanding of their own students (Magnusson et al., 1999). This highlights the importance of selecting tasks that

make students' thinking visible to teachers (Remillard, 2000). In addition, as learners teachers will need student tasks that will address their own prior ideas. For example, the literature tells us that many teachers believe students need only to be active in order to learn (Meyer, 1997). Ms. Shirley relied on activity – fun and excitement – as evidence of learning. Materials could actively address teachers' prior ideas. In this case, a focus on how to determine their students' ideas before and after lessons would be appropriate.

To engage teachers in planning and teaching developers must be quite explicit in describing lessons – how to enact specific strategies, guide discussions, or illustrate phenomena – but also, *why* they should attend to specific aspects of tasks and *how* they can support student learning. This includes consistently describing the specific and long range learning goals of each task. Developers also need to better predict student responses and describe outcomes. To develop teachers' PCK developers need to focus teachers' attention on student thinking, particularly their own students' thinking. Student activities that clearly focus on cognitive products can be included to help teachers learn how to guide students' thinking as well as doing in inquiry. To match teachers' learning needs developers need to reconsider the variety and amount of activities they ask teachers to enact. Challenges seen suggest developers should consider smaller but key initial steps such as questions or tasks that elicit students' ideas and encourage students to consider others' ideas. Lesson that help teachers learn inquiry would benefit students also. For example, lessons with one clear goal, focused questions, and support for how to discuss this idea would help teachers and students focus on student thinking. Finally, when scenarios intended illustrate how a lesson might play out are also designed to be read aloud with students they appear to match teachers' natural inclination to read such scenarios to their students (Collopy, 1999).

Writing materials to be educative for teachers will not be easy, but neither is learning and teaching inquiry. If designers do not paint a picture of inquiry through their lesson descriptions, teachers will not see it. Teachers, quite understandably, will use their prior knowledge of teaching to makes sense of lessons. Moreover, it will be important, yet challenging, to leave room for teachers to participate in planning and teaching in thoughtful ways. This will require developers to plan for teachers' learning in addition to students' learning. Designers need to focus not on what teachers need to know to get it right, but rather, what teachers need to learn to take an active role in enacting inquiry with their students.

Conclusion

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. Through a better understanding of how inquiry teaching develops over time, what teachers learn, and how materials can help, we can begin to develop effective resources to support teachers' work with students. Wonderful materials for students are becoming available but if teachers cannot use them as intended they will not have the impact on student learning hoped for. Teachers are encouraged to use inquiry teaching methods but are rarely given explicit support to guide them in how or why to guide their students in investigating questions, working collaboratively, or engaging in thoughtful discussions. Although researchers can work closely with small numbers of teachers to support their efforts this is not possible on a large scale. Reform materials will need to incorporate explicit supports for teachers' learning. Designers need to carefully consider teachers' thinking and learning needs, as well as students', as they develop innovations to impact student learning.

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