INVESTIGATING TEACHER LEARNING SUPPORTS IN HIGH SCHOOL BIOLOGY TEXTBOOKS TO INFORM THE DESIGN OF EDUCATIVE CURRICULUM MATERIALS

Carrie J. Beyer
Cesar Delgado
Elizabeth A. Davis
Joseph S. Krajcik

School of Education
University of Michigan

contact: cjbeyer@umich.edu

A paper presented at the April 2007 annual meeting of the National Association for Research in Science Teaching, New Orleans.

This research is funded by a Centers for Learning and Teaching (CLT) grant #0227557. However, any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors. We greatly appreciate the interest and cooperation of the teacher who made this research possible. We also thank the CASES research group at the University of Michigan and members of the Center for Curriculum Materials in Science for their help in thinking about these issues.

INVESTIGATING TEACHER LEARNING SUPPORTS IN HIGH SCHOOL BIOLOGY TEXTBOOKS TO INFORM THE DESIGN OF EDUCATIVE CURRICULUM MATERIALS

Carrie J. Beyer, Cesar Delgado, Elizabeth A. Davis, & Joseph S. Krajcik
University of Michigan

Abstract: Previous reform efforts have shown the need to support teachers' learning about reform-oriented practices. Educative curriculum materials are one potential vehicle for supporting teachers' learning about these practices. Educative curriculum materials include supports that are intended to promote both student *and* teacher learning. However, little is known about the extent to which existing curriculum materials provide support for teachers and the ways they can be improved. In this study, eight sets of high school biology curricula were reviewed to determine their potential for promoting teacher learning. Design heuristics for educative curriculum materials developed by Davis and Krajcik (2005) were adapted for use as evaluation criteria. From this analysis, several themes emerged. First, the materials tended to provide support for teachers' subject matter knowledge and pedagogical content knowledge for students' ideas (e.g., misconceptions) but rarely for scientific inquiry. Second, the materials contained several implementation guidance supports but far fewer rationales for instructional decisions, which are an important feature of educative curriculum materials. Finally, the quality of support varied widely, differing in its degree of relevance, pedagogical helpfulness, and depth as well as in how explicit, embedded, and integrated the support was in the materials. The paper concludes with implications for the design of educative curriculum materials.

Curriculum materials play a fundamental role in classroom instruction. These materials often contain content and skills for students to learn, detail connections among ideas, provide contexts for teaching these ideas, and suggest sequences for activities (Remillard, 2000). Teachers are accustomed to using these tools to guide their planning and enactment of lessons (Ball & Cohen, 1996). Even more, teachers teaching outside their content area and teachers entering the field tend to rely extensively on such materials (Ball & Feiman-Nemser, 1988; Grossman & Thompson, 2004). "Of all the different instruments for conveying educational policies, [curriculum materials] exert perhaps the most direct influence on the tasks that teachers actually do with their students each day in the classroom" (Brown & Edelson, 2003, p.1).

Using curriculum materials to convey educational policy in science education is not a new idea. In the 1950s and early 1960s, content experts developed novel curriculum materials in an attempt to improve science instruction (Welch, 1979). These science curriculum materials provided updated content, greater variety of media and materials, and increased emphasis on the processes of science. While those curriculum materials were widely adopted, the curriculum reform efforts were largely ineffective. These materials failed to effect change because curriculum developers neglected to consider the role teachers play in enacting the materials (Welch, 1979; Stake & Easley, 1978). Even though these materials were designed to support student learning, they failed to help teachers understand the core vision or how to make productive adaptations that would not misrepresent the vision (Krajcik, Mamlok, & Hug, 2001).

Current reform efforts call for educators to develop students' understandings and abilities with regard to scientific inquiry (American Association for the Advancement of Science [AAAS], 1993; National Research Council [NRC], 1996, 2000). Teaching science as inquiry entails engaging students in asking scientific questions, designing and conducting investigations to answer those questions, and constructing explanations based on evidence (Krajcik, Blumenfeld, Marx, & Soloway, 2000). To support teachers in implementing reform-oriented practices, researchers have begun to examine the role that curriculum materials might play in supporting teachers' learning about these practices (Schneider, Krajcik, & Blumenfeld, 2005). Such materials have been termed *educative* curriculum materials (Davis & Krajcik, 2005; Heaton, 2000). Research has shown that teachers who use educative curriculum materials can develop their knowledge of content and learners and expand their repertoire of instructional practices (Schneider & Krajcik, 2002; Schneider, 2006).

Despite the potential of educative curriculum materials, little is known about the extent to which existing science curricula support teacher learning. Project 2061 has conducted reviews of science textbooks using research-based evaluation criteria, but their criteria primarily focus on how well curriculum materials promote students' learning of science, not teachers' learning of how to teach science (AAAS, 2005; Kesidou & Roseman, 2002). This study examines the quantity and quality of teacher learning supports within currently available biology high school curriculum materials. The findings from this study inform the design of future curriculum materials, thereby supporting reform efforts.

Theoretical Framework

Developing expertise in science teaching entails developing an integrated understanding of multiple knowledge components that are crucial for promoting students' learning of science. Teaching is complex, and thus teachers are in need of support to help them develop a coherent, well-organized framework of knowledge. Curriculum materials with embedded learning supports may play an important role in supporting teacher learning. These ideas are explored below.

Dimensions of Teacher Learning

Teaching is a complex practice. In order to deal with this complexity, teachers need to develop their knowledge in a variety of domains. Like students, teachers need to develop a robust understanding of subject matter content, which includes knowledge of the concepts, practices, and beliefs of a disciplinary field (Schwab, 1964). However, unlike students, teachers must also develop knowledge related to the effective instruction of content. Two domains of specialized teacher knowledge are pedagogical knowledge and pedagogical content knowledge (PCK) (Shulman, 1986). While pedagogical knowledge is general teacher knowledge and is independent of subject matter, PCK is topic- or discipline-specific. More specifically, PCK entails knowledge of learners, including an understanding of the difficulties students face in learning the subject matter and how to deal with those difficulties (Borko & Putnam, 1996; Grossman, 1990; Shulman, 1986). It includes knowing strategies for identifying, interpreting, and working with students' likely ideas about a subject matter. PCK also entails knowledge of effective instructional strategies for representing the subject matter to help students construct understanding (Grossman, 1990; Shulman, 1986). Such knowledge goes beyond having a repertoire of interesting classroom activities and representations. It entails having a meta-level understanding of how to effectively use such instructional strategies for specific topics. It also includes having "standards by which [to] evaluate the appropriateness" of different representations (McDiarmid, Ball, & Anderson, 1989, p. 198) and knowing why particular strategies are pedagogically appropriate for promoting student learning.

Building upon the construct of PCK, Magnusson, Krajcik, and Borko (1999) have identified and described five essential components of PCK for *science* teaching. These components include knowledge of orientations toward science teaching, learners, curriculum, instructional strategies, and assessment. A further elaboration on the concept of PCK for science teaching is PCK for scientific inquiry (Davis & Krajcik, 2005; Zembal-Saul & Dana, 2000). This construct entails teachers' knowledge of orientations consistent with scientific inquiry, students' understandings of inquiry, inquiry-oriented curriculum materials, instructional strategies for fostering inquiry, and assessment techniques for inquiry. Having teachers develop their knowledge of teaching science as inquiry is fundamental to supporting current reform efforts, which call for educators to develop students' understandings and abilities with regard to inquiry (AAAS, 1993; NRC, 1996; 2000). Therefore, in order to promote students' learning of reform-oriented science, teachers need to develop expertise in many different types of knowledge.

Role of Curriculum Materials in Fostering Teacher Learning

Recent literature in science education has begun to examine the role that educative curriculum materials might play in fostering teacher learning (Schneider & Krajcik, 2002; Schneider, 2006). Even though several forms of professional development can promote teacher learning, embedding teacher learning opportunities within curriculum materials is a fruitful option for many reasons (Ball & Cohen, 1996). Curriculum materials are connected to teachers' daily work and thus can situate teachers' learning in their own practice (Putnam & Borko, 2000) and provide ongoing support (Collopy, 2003). They may also foster teacher learning on a large scale, unlike other reform efforts aimed at state and district levels (Schneider & Krajcik, 2002). Thus, curriculum materials may be used as effective tools in promoting change not only in what is taught in science classrooms (as earlier reforms did) but also in how science is taught.

Educative curriculum materials are designed explicitly to promote teachers' learning about teaching as they use the materials to foster students' learning about the subject matter (Davis & Krajcik, 2005). Pedagogical supports within educative materials often appear separately from the student materials, in teacher guides or in annotated teacher editions of textbooks. To promote teacher learning, these materials are "designed to speak to teachers, not merely through them" by engaging teachers in "the ideas underlying the writers' decisions and suggestions" (Remillard, 2000, p. 347). Such materials also foster teacher learning by helping teachers make productive and informed decisions about how to respond to students' encounters with the instructional activities (Remillard, 2000). Additionally, educative materials that are consistent with reform documents can help teachers learn about new ways of teaching science, practice these new ideas in their classroom instruction, and reflect upon these experiences (Borko & Putnam, 1996). In these ways, curriculum materials that are designed with explicit pedagogical support can foster the development of teachers' knowledge and practice and thus ultimately contribute to reform efforts.

On the other hand, curriculum materials that are not educative for teachers tend to provide activities and tasks aimed at aiding student learning exclusively. Support in these types of materials is often limited to logistical help such as enumeration of required supplies or estimated time for lessons. Such materials emphasize "the outcomes of teaching and not the rationales, assumptions, or agendas supporting them, discouraging teachers from engaging the ideas underlying the writers' decisions and suggestions" (Remillard, 2000, p. 347). This level of support is insufficient for most teachers enacting reform-oriented instruction because teaching science as inquiry entails ambitious learning goals for students and thus is complex and difficult for teachers to enact (Marx, Blumenfeld, Krajcik, & Soloway, 1997; Roehrig & Luft, 2004). Many teachers have not experienced inquiry-based instruction as learners and thus need guidance in enacting this type of instruction (Windschitl, 2002). Those who have experienced inquiry science as learners may have undergone an "apprenticeship of observation" (Lortie, 1975), gaining little insight into the teacher's rationales and instructional decisions.

Purpose of the Present Study

In order to assess the extent to which existing curriculum materials provide support for teachers and the ways they can be improved, we evaluated eight sets of high school biology curricula to determine their potential for promoting teacher learning, focusing primarily on teacher guides and teacher editions of the textbook. We derived the evaluation criteria from Davis and Krajcik's (2005) design heuristics for educative curriculum materials. The research questions guiding our study include the following:

1. What is the relative frequency of different educative supports across curricula?
    a. What is the relative frequency of support for subject matter knowledge, PCK for science topics, and PCK for inquiry?
    b. What is the relative frequency of rationales and implementation guidance supports?
2. What is the quality of educative supports across curricula?

By uncovering the strengths and weaknesses of existing biology curricula in providing educative support for teachers, this study contributes to the field's understanding of how to design improved curriculum materials. Better curriculum materials can in turn contribute to the reform of science education.

Methods

This section describes the textbooks included in the curriculum review and the criteria included in the evaluation procedure. The procedures for analysis and for ensuring reliability of results are also detailed below.

Textbooks and Topics Examined

This curriculum review focuses on eight science programs written for introductory biology high school students, hereinafter identified as P1-P8. (Appendix A lists the programs reviewed in this evaluation.) Four of the eight programs (P1, P5, P6, and P7) were funded by the National Science Foundation (NSF). Additionally, P1, P5, and P7 provided support in the form of a teacher's guide keyed to but separate from the student textbook, while the other programs employed a teacher's edition of the student textbook with wraparound text aimed at teachers.

The market share of the programs varied widely. P3 and P8 were two of the top three most commonly used high school biology textbooks in the year 2000 (Weiss, Banilower, McMahon, & Smith, 2001, p. 84), while P5, P6, and P7 together accounted for 2% or less of the market share in 2000 (Weiss et al, p. 83). All programs are recent editions, wherein seven were edited in 2003 or later and one (P7) edited in 1998. None of these materials were developed following the publication of Davis and Krajcik's (2005) design heuristics, and none were necessarily intended to be educative or inquiry-oriented. Most of the programs have been recently developed, being in their first, second, or third edition, while one program (P6) is in its tenth edition, with its first edition dating back to 1963.

Our sampling procedure narrowed the review to two topics: (a) natural selection and evolution and (b) environment and ecology. These are important topics contained in the national science education reform documents (AAAS, 1993; NRC, 1996). In order to compare the total number of different educative supports across materials, 50 pages were evaluated for each topic within each textbook. Totals from textbooks with fewer than 50 pages on a topic were proportionally scaled up for purposes of comparison. Within each program, teacher materials that were keyed to the student content were included in the analysis, that is, teacher editions of textbooks with wraparound text and teacher guides. Stand-alone materials not correlated to student content, such as laboratory manuals, were not coded but were described during the qualitative analysis of the materials (described below). These ancillary materials usually did not have many supports for teacher learning as defined by the evaluation criteria.

Evaluation Procedure

Twenty-five evaluation criteria were used in this analysis, and they corresponded to different types of educative support that was coded for in the materials. These evaluation criteria, or *types of support*, were derived from Davis and Krajcik's (2005) design heuristics for educative curriculum materials (see Appendix B), which were informed by recommendations put forth by Ball and Cohen (1996) and Brown and Edelson (2003) as well as by the limited empirical work that has been conducted on this topic (e.g., Collopy, 2003; Petish, 2004; Schneider & Krajcik, 2002; Wang & Paine, 2003). These evaluation criteria were grouped into nine *categories*, corresponding to the original nine design heuristics, and were operationalized in order to create parallel *forms of support* across the categories.

More specifically, within each category, evaluation criteria were organized around baseline features and encompassed two specific *forms of teacher support*: rationales and implementation guidance.[1] Baseline features are curriculum components upon which educative supports can be built. Implementation guidance is one form of educative support that focuses on helping teachers know *how* to use instructional approaches and activities in productive ways by making explicit their salient features. Implementation guidance also helps teachers adapt these approaches to achieve productive instructional ends (Davis & Krajcik, 2005; Remillard, 2000; Schneider & Krajcik, 2002). Rationale is second form of support that presents explicit justification for the inclusion of particular instructional approaches in the curriculum and explains *why* these are pedagogically and scientifically appropriate. This type of support is educative because it makes the curriculum developers' pedagogical judgments and curricular decisions visible to teachers. Rationales provide opportunities for teachers to examine the assumptions and agendas underlying the instructional approaches embodied in the curriculum materials (Ball & Cohen, 1996; Davis & Krajcik, 2005, Heaton, 2000; Remillard, 2000). The classification of evaluation criteria by form of support and by category is found in Appendix B.

---

[1] All nine categories contained these two forms of support, except Category 9, which lacks a criterion dealing with implementation guidance. Implementation guidance is not applicable for supporting teachers' subject matter knowledge, since the additional content information intended to support teacher learning is not implemented in the classroom. Additionally, criterion 9B, which deals with providing teachers with science content information, does not fall under either rationale or implementation guidance.

The nine categories were further grouped into three *domains* of teacher knowledge: subject matter knowledge, PCK for science topics, and PCK for scientific inquiry. These three domains of teacher knowledge were identified from the research literature as important areas in need of support (Collopy, 2003; Heaton, 2000) but were not intended to be exhaustive in coverage or domain (Davis & Krajcik, 2005). Support for PCK for science topics corresponded to three categories: support for teachers in engaging students with topic-specific scientific phenomena, using scientific instructional representations, and anticipating, understanding, and dealing with students' ideas about science. Support for PCK for scientific inquiry included five categories: support for teachers in engaging students in asking and answering questions, collecting and analyzing data, designing investigations, making explanations based on evidence, and communicating scientifically. Finally, support for teachers' subject matter knowledge corresponded to one category: support for teachers in developing their subject matter knowledge. Examples of support for each domain are provided in the results section.

The second research question, concerning the quality of support for teachers, emerged during analysis, as reviewers noted large qualitative differences between materials. The evaluation criteria did not include a rating scheme or rubric with which to evaluate the quality of support. Therefore, the quality of the educative supports present in each set of materials was instead evaluated holistically and qualitatively, using rich description and analysis.

Analysis

Eight reviewers participated in this study. Reviewers included university faculty and graduate students—all with knowledge of the research on science learning and teaching, three with biology backgrounds, and two with former high school biology teaching experience. All analysts independently evaluated each textbook's teacher edition or guide using the criteria outlined in Appendix B. The reviewers recorded and classified each instance of educative support found in the materials.

After coding the materials, descriptive statistics were used to determine how often each set of curriculum materials supported each domain of teacher knowledge. Patterns were then identified across the corpus of curriculum materials with regard to the types and frequency of educative support present.

To complement this quantitative analysis, reviewers wrote descriptive narratives that characterized the quality of the most common educative supports in each set of teacher materials. These narratives included excerpts from the materials that exemplified these supports—characterized as weak or strong supports—and described where the supports were typically found in the materials. Thus, the narratives provide a rich description of what the educative supports looked like in the materials, their quality, and to what extent they were accessible to teachers.

Reliability of Results

Prior to the analysis, reviewers practiced jointly and independently applying the criteria to sections of text drawn from both NSF-funded and commercially developed materials, using topics other than the ones selected for the analysis. Reviewers then compared their results, developing a shared understanding of the criteria. During the actual evaluation process, additional discussions took place via face-to-face group meetings, email, and an on-line posting board. These discussions allowed reviewers to resolve any ambiguity as a group in the application of the evaluation criteria. An on-line record was kept during the training and subsequent analyses, documenting the clarifications made to the meaning of the evaluation criteria. Reviewers revisited earlier classifications potentially impacted by these modifications, to ensure that coding did not vary over time as the criteria were refined.

To further enhance the validity of our results, each reviewer also served as a second analyst on another set of materials. The different sets of curriculum materials were rotated among all eight reviewers. This system of rotation enabled us to obtain overlapping inter-rater reliability among all eight coders rather than between pairs of coders. The second analyst independently evaluated a minimum of 10 pages on each topic (20% of the data). All reviewers achieved 80% inter-rater reliability or higher on at least 10% of the data and subsequently resolved all disputes through discussion. Finally, the qualitative narrative descriptions characterizing each set of curriculum materials were written by the primary coder and reviewed by the secondary coder. Disagreements were resolved through discussion.

The principal source of disagreement between reviewers lay not in identifying instances of educative support but in classifying each instance according to the criteria. For example, teacher support for implementing an activity involving the construction of a model that illustrates a phenomenon might be classified as support for engaging students in phenomena (Category 1) or support for using an instructional representation (Category 2). When discrepancies arose in reviewers' coding, discussion often established that the educative support pertained to both evaluation criteria. Despite these disagreements, the magnitude of uncertainty in the frequencies and percentages for criteria presented in the results section is likely to be small, since inter-rater reliability was 80% or above for each set of curriculum materials. At the level of categories and knowledge domains, reliability is likely even greater, since disagreement in coding typically occurred between two criteria within the same category, or between criteria in different categories but within the same domain of teacher knowledge.

Other considerations with regard to the representativeness of the results pertain to the sampling of the materials. There may have been slight differences in the distribution of educative supports between the two topics that were evaluated and the rest of the topics in the materials. Had different topics been selected, the relative frequency of supports may have varied. A final consideration in viewing the results below deals with the steps taken to compare the number of instances of support across materials. In textbooks having fewer than 50 pages on a topic, which occurred in P1, P2, and P7, the actual counts were extrapolated linearly from the actual number of pages to 50 pages. Thus, the final frequencies reported in these materials may not be entirely representative of the actual frequencies if the materials were to have 50 pages on each topic. With these considerations in mind, findings are summarized below and illustrated with examples from the curriculum materials.

Results

This section presents findings on the quality of a broad range of contemporary curriculum materials for high school biology. The inclusion of two out of the three most commonly used textbooks, as well as less widely-adopted NSF-funded curricula, makes the materials reviewed fairly representative of curriculum materials for high school biology as a whole. The relative quantity and quality of support for teacher learning across eight sets of curriculum materials is reported. Six curricular programs evaluated in this study are also included in Project 2061's recent evaluation of high school biology textbooks (AAAS, 2005), allowing for a more complete characterization of the individual programs and of high school biology materials in general.

Question 1a: What Is the Relative Frequency of Support for Subject Matter Knowledge, PCK for Science Topics, and PCK for Inquiry?

As mentioned earlier, evaluation criteria focused on support for three teacher knowledge domains: teachers' subject matter knowledge, PCK for science topics, and PCK for scientific inquiry. Table 1 presents the total number of instances of educative support for each teacher knowledge domain across all eight curricular programs.

Table 1
Frequency and Percentage of Support for Teacher Knowledge Domains Across Programs

Teacher Knowledge Domain	Frequency of Support	Percentage of Support
PCK for Topics	318	55%
PCK for Inquiry	72	13%
Subject Matter Knowledge	183	32%
Total	573	100%

Support for PCK for science topics was the most prevalent domain of teacher knowledge supported in the materials, accounting for 55% of all instances of educative support. The next most common support was for teachers' subject matter knowledge (32% of all support) followed by PCK for scientific inquiry (13% of all support). A further breakdown by category and criterion follows, along with illustrative examples.

Support for PCK for Science Topics (Categories 1-3)

Support for PCK for science topics was the most common knowledge domain supported in the curriculum materials, representing 55% of all instances of support found in the materials. Support for PCK for topics entails providing guidance for teachers in three categories: engaging students with topic-specific scientific phenomena (Category 1), using scientific instructional representations (Category 2), and anticipating and dealing with students' ideas about science topics (Category 3). Table 2 presents the frequency and percentages of support by category and criterion for this domain of teacher knowledge.

Table 2
PCK for Topics: Frequency and Percentage of Support By Criterion Across Programs

Category/Criterion	Frequency of Support	Percentage of Support within PCK for Topics	Percentage of Support Across All Knowledge Domains
1. Support Teachers in Using Scientific Phenomena			
A. Rationale for using specific phenomena	38	12%	7%
B. Guidance on using specific phenomena	23	7%	4%
C. Guidance on pitfalls with specific phenomena	23	7%	4%
D. Guidance on sequences of tasks for phenomena	3	1%	<1%
Total Across Programs	87	27%	15%
2. Support Teachers in Using Representations			
A. Rationale for using specific representations	26	8%	4%
B. Guidance on using specific representations	46	15%	8%
Total Across Programs	72	23%	12%
3. Support Teachers in Regards to Students' Ideas			
A. Rationale for attending to students' ideas	5	2%	<1%
B. Guidance on identifying students' ideas	99	31%	17%
C. Guidance on dealing with students' ideas	55	17%	10%
Total Across Programs	159	50%	28%
Total Support for PCK for Topics Across Programs	318	100%	55%

Within PCK for science topics, support for attending to students' ideas was the most common category of support (Category 3, 50% of all instances of educative support within this domain), followed by support for using scientific phenomena (Category 1, 27%) and using representations (Category 2, 23%). Each of these categories is further described below, with examples.

Category 1 – Supporting teachers in using scientific phenomena. Over a quarter (27%) of the instances of educative support coded for PCK for topics across all programs had to with Category 1 (see Table 2). The most common type of support within this category was rationales for engaging students in real-world phenomena, comprising 12% of the total instances coded within PCK for topics. An example of this type of support includes the following rationales, which explain why teachers might want to have students examine live specimens using a microscope or hand lens:

> "This investigation allows students to sharpen their observational skills while working with a variety of organisms. Positioned at the beginning of the chapter, the investigation sets the stage for discussing the web of life" (P6, p. 20).

This excerpt exemplifies the type of support that teachers commonly received when they were provided with opportunities to engage students in real-world phenomena.

Category 2 – Supporting teachers in using representations. Approximately 23% of the instances of educative support coded for PCK for topics across programs concerned supporting teachers in using instructional representations (see Table 2). Support within this category often took the form of recommendations that aimed to help teachers effectively use specific instructional representations described in the materials. This type of implementation guidance support comprised 15% of the total instances coded within PCK for topics. The following excerpt illustrates this type of support by explaining to teachers how they might use a photograph in the textbook to illustrate interactions between biological and physical factors in an ecosystem:

> Provide students with the opportunity to discuss what the bird is doing. Cedar waxwings like the high sugar content of ripening fruit (in this case, mountain ash berries). Ask students what clues this fact might give them about when the bird will be most visible. *Summer into early fall when fruit is ripe.* As you develop the concepts of biotic and abiotic factors use this photo to make these concepts more real. The bird and the ripening fruit are biotic factors. The time of year, controlled by light and climate, is an abiotic factor that affects the time food is available to the bird. Later in the chapter, have students write or discuss how the photograph sums up the big picture of ecology. (P3, p. 34)

This excerpt aims to help teachers effectively use this representation by pointing out the salient features of the photo and providing suggestions for its use. This example illustrates the type of support that most materials provided teachers with regard to helping them use representations.

Category 3 – Supporting teachers in regards to students' ideas. Half of all instances of educative support coded within PCK for topics corresponded to Category 3. Within this category, support for helping teachers identify students' ideas and deal with those ideas in their instruction were two common types of support, constituting 31% and 17% of all instances coded within PCK for topics, respectively (see Table 2). These percentages show that almost half of the educative features that helped teachers identify students' ideas gave no guidance for how to deal with them. Additionally, across all three teacher knowledge domains, these supports were the second and third most frequently encountered in the curriculum materials. The following excerpt highlights an example of support for identifying and dealing with students' ideas:

> Address Misconceptions: Some students may have the misconceptions that all areas in tropical regions receive a great amount of rainfall all the time. Explain that it is true that many areas have abundant rainfall because of frequent thunderstorms caused by local heating of the air. Currents in the atmosphere, however, are extremely complex, and in some regions wind patterns result in much less precipitation than is found in regions with tropical rain forests. The result is that the tropics contain dry forests, savannas, and even deserts. (P8, p. 100)

This passage supports teachers by alerting them to a common alternative idea about the characteristics of tropical regions and suggests a strategy for remediation: that teachers tell students the correct scientific idea.

While the example above presents possible student ideas directly to the teacher, the next example illustrates how some supports guided teachers in determining their *own* students' ideas.

> Discussion Questions: This discussion should give you an opportunity to determine student preconceptions and their current level of understanding. To facilitate this discussion you may wish to ask the following:
>
> - What is a habitat? What are some examples?
> - What is an ecosystem? What are some examples?
> - What are some of the features and/or components of an ecosystem?
> - Why is Earth itself considered an ecosystem? (P7a, p. 4)

Questions of this type were common, although in some cases the purpose of the questions was left unstated. In sum, support for identifying and dealing with students' ideas was frequent and took several different forms. The quality of the different types of support for attending to students' ideas is addressed further in the results for research question 2.

Support for Subject Matter Knowledge (Category 9)

Teachers' subject matter knowledge was the second most common domain of teacher knowledge supported in the materials, after PCK for topics, accounting for 32% of all instances of educative support (see Table 1). This domain consisted of only one category, that is, support for the development of teachers' knowledge of the subject matter (Category 9). The most common type of support within this category was providing teachers with science content information beyond the level of understanding required by students. Additionally, across all three teacher knowledge domains, this criterion was the most frequently encountered in the curriculum materials, constituting nearly one-third of all educative supports. On the other hand, rationales for the importance of strong teacher content knowledge were almost entirely absent from the materials examined. Table 3 presents the frequency and percentages of support by criterion for this domain of teacher knowledge.

Table 3
Subject Matter Knowledge: Frequency and Percentage of Support By Criterion Across Programs

Category/Criterion	Frequency of Support	Percentage of Support within Subject Matter Knowledge	Percentage of Support Across All Knowledge Domains
9. Support Teachers in Building Content Knowledge			
A. Rationale for having strong content knowledge	1	1%	<1%
B. Science background knowledge for teachers	182	99%	32%
Total Across Programs	183	100%	32%

Support for teachers' subject matter knowledge commonly entailed snippets of additional information related to ideas in the student text. An example of this type of support reads:

> Any chlorophyll-containing organism can use light energy to make its own food. Much of the photosynthesis on the earth is carried out by algae and cyanobacteria. The discussion here is limited to green plants for simplicity. (P6, p. 93)

This example provides teachers with the opportunity to develop a deeper understanding of photosynthesis discussed in the student materials. Most instances provided teachers with additional information but did not explicitly state how ideas in the student textbook had been simplified, as the example above does.

Support for PCK for Scientific Inquiry (Categories 4-8)

PCK for scientific inquiry was the domain of teacher knowledge that received the least amount of support across all the materials, accounting for only 13% of the total support (see Table 1). Support for PCK for inquiry entailed supporting teachers in engaging students in asking and answering scientific questions (Category 4), collecting and analyzing data (Category 5), designing investigations (Category 6), making explanations based on evidence (Category 7), and communicating scientifically (Category 8). Table 4 presents the frequency and percentages of support by category and criterion for this domain of teacher knowledge.

Table 4
PCK for Inquiry: Frequency and Percentage of Support By Criterion Across Programs

Category/Criterion	Frequency of Support	Percentage of Support within PCK for Inquiry	Percentage of Support Across All Knowledge Domains
4. Support Teachers in Engaging Students in Questions			
A. Rationale for using particular questions	21	29%	4%
B. Guidance on using particular questions	1	2%	<1%
C. Guidance on having students use their questions	3	4%	1%
Total Across Programs	25	35%	4%
5. Support Teachers in Fostering Data Collection/Analysis			
A. Rationale for data collection/analysis approaches	2	3%	<1%
B. Rationale for having students collect data	2	3%	<1%
C. Guidance on using specific approaches	3	4%	1%
D. Guidance on using specific data collection and analysis approaches across multiple topic areas	0	0%	0%
Total Across Programs	7	10%	1%
6. Support Teachers in Helping Students Design Investigations			
A. Rationale for having students design studies	2	3%	<1%
B. Guidance on having students design studies	4	5%	1%
Total Across Programs	6	8%	1%
7. Support Teachers in Engaging Students in Explanations			
A. Rationale for using approaches for explanations	0	0%	0%
B. Rationale for fostering explanation construction	0	0%	0%
C. Guidance on using approaches for explanations	3	4%	1%
Total Across Programs	3	4%	1%
8. Support Teachers in Promoting Scientific Communication			
A. Rationale for using communication approaches	16	22%	3%
B. Guidance on using communication approaches	15	21%	3%
Total Across Programs	31	43%	5%
Total Support for PCK for Inquiry Across Programs	72	100%	13%

Within PCK for inquiry, support for promoting scientific communication was most commonly coded (Category 8, 43% of all instances of educative support within this domain), followed by support for engaging students in asking and answering scientific questions (Category 4, 35%). In the entire study of all eight curriculum materials, only seven or fewer instances of support were found for each of the remaining categories. The two more common categories (4 and 8) are further described below. Given the infrequency of these supports, the illustrative excerpts should be viewed as exemplars rather than typical examples.

Category 4 – Supporting teachers in engaging students in questions. In Category 4, the most common type of support was rationales for using the questions provided in the teacher materials and consisted of 29% of the total support within PCK for inquiry (see Table 4).

The following exemplar illustrates how some materials provided teachers with explicit justification for the use of specific questions during instruction:

> Ask students to imagine what would happen if any one or two of these types of workers disappeared. This question is intended to get students thinking about the consequences of an extinction event. (P7a, p. 23)

This excerpt helps teachers understand why they might want to ask students certain questions during instruction, thereby supporting teachers in engaging students in asking and answering questions.

Category 8 – Supporting teachers in promoting scientific communication. The two evaluation criteria in Category 8 were equally common in the curriculum materials (see table 4). Support for promoting scientific talk included helping teachers understand why suggested approaches for fostering communication were scientifically and pedagogically appropriate, which comprised 22% of the total instances coded within PCK for inquiry. An example of this support includes the following explanation stating why teachers might want to use a particular strategy for a team project:

> The story can be written as a team project by having each student write about how one of the scientific disciplines would work with the fossil find. You may want to add the requirement that the specialist may not write about his or her own evidence. This strategy will ensure that the students convey their information to their teammates and that they are able to learn from each other. (P5, p.73)

This excerpt provides teachers with explicitly stated reasons for the suggested communication approaches, thereby facilitating teachers' learning about this aspect of inquiry-oriented teaching.

The other type of support within this category consisted of guidance for teachers in implementing and adapting communication approaches with their students. For example, one program encouraged teachers to have students work in groups as they completed an activity (a common suggestion in the curriculum materials) but then also provided guidance on how to help students engage in productive conversations as they worked in these groups. It reads,

> Have the students in each team concentrate on listening to and respecting each other's ideas. Make clear to the students that this is one goal of the activity. You might decide to write 'Listen to your teammates' on the board as a reminder. As the activity proceeds, keep track of how well the students are listening to each other. If a team seems to be having trouble with one or two dominant individuals, model the types of questions and etiquette expected of the dominant individuals by asking another team member, What ideas do you have about how this event should be placed? (P5, p. 66)

This example provides detailed suggestions for teachers in fostering productive conversations during group work, helping teachers learn how to engage students in scientific communication.

Summary of Support Across Teacher Knowledge Domains

In sum, PCK for topics was the most commonly supported teacher knowledge domain, and within this domain, supports for identifying and working with students' ideas about science were the two most prevalent types of support. Support for teachers' subject matter knowledge was the next most frequently supported domain, and providing teachers with elaborated science content information was the most common type of support within this domain and in the materials, overall. Support for PCK for inquiry was the least frequently supported teacher knowledge domain and was generally low across all five categories within this domain. Two

NSF-funded curricula, P5 and P7, differed notably from the other programs. They had the most support for PCK for inquiry, averaging 30 instances of support in the sampled materials in comparison to 5 or fewer instances of support identified in the other programs. Additionally, these two programs provided the most support for teachers across all categories of support, providing over 100 instances of support in the sampled materials, in contrast to an average of 57 instances of support found in the other programs. These findings and others dealing with comparisons among materials are discussed further elsewhere (Beyer, Delgado, Davis, & Krajcik, 2006).

Question 1b. What Is the Relative Frequency of Rationales and Implementation Guidance Supports?

In addition to examining the frequency of support across the three teacher knowledge domains, the *form of support* (implementation guidance vs. rationale) was also examined. Implementation guidance helps teachers know *how* to use suggested instructional approaches and activities in productive ways. Rationales present explicit justification for including the instructional approaches in the curriculum by explaining *why* they are pedagogically and scientifically appropriate. Across the eight sets of curriculum materials, implementation guidance was by far more prevalent than rationales. Implementation guidance comprised 48% of the total instances of support coded, while rationales accounted for only 20%. (Subject matter support for teachers [Category 9B], which was classified neither as rationale or implementation guidance, made up the remaining 32% of support.) Table 5 presents the total instances of educative support for each form of support across the entire data corpus analyzed.

Table 5
Frequency and Percentage of Support for Different Forms of Support Across Programs

Form of Support	Frequency of Support	Percentage of Support
Implementation Guidance	277	48%
Rationale	115	20%
Subject Matter Support	183	32%
Total	573	100%

These findings show that the curriculum materials tended to provide more support for *how* to use or adapt particular instructional approaches than support explaining *why* these approaches might be useful in their practice. Thus, there were relatively few supports enabling teachers to examine the assumptions and agendas underlying the approaches embodied in the curriculum materials.

With regard to rationale, one set of materials supported teachers in using a compost column to help students explore a small-scale ecosystem by explaining why having students experience this phenomenon was important. It reads:

> Studying composting can lead to understanding the relationship between biology and energy transfer in the environment. This activity also provides a solid example of how individuals can have a positive effect on the environment while decreasing the amount of water. (P1, p. 48)

In addition to these rationales, the materials included implementation guidance to help teachers use this phenomenon with their class. For example, in helping students use the columns to study producers, consumers, and decomposers, the materials explained how to find these organisms in the columns. It reads,

> Finding creatures in the compost can be aided in several ways. Putting the compost in a white enamel pan and then separating the material is one way to make it easy to see the larger animals. An old technique for separating the organisms from the compost is a funnel with a heat source above and a container below it… (P1, p. 135)

These excerpts highlight examples of both rationales and implementation guidance support that were found in the materials. However, despite having both forms of support, curriculum materials often provided fewer opportunities for teachers to see *why* specific approaches might be useful than to understand *how* to use the instructional approaches in their practice.

Question 2: What Is the Quality of Educative Supports Across Curricula?

The quantity of support is not the only consideration in determining the materials' potential for promoting teacher learning. The quality of support is also an important consideration, particularly since it differed within and among materials. The perceived quality of the most common types of support for each set of curriculum materials was described in the narrative reports. The quality of these educative supports is described below with illustrative examples drawn from the teacher materials.

Range of Support With Regard to Relevance, Pedagogical Helpfulness, and Depth

The curriculum materials exhibited a range of support that varied along several dimensions. The educative supports in the materials varied in their degree of relevance for teachers, that is, in terms of their applicability to or connection with the core concepts in the student text. The supports also differed in regard to their degree of pedagogical helpfulness, that is, in the extent to which teachers were provided with effective and reliable guidance that has been shown to be dependable through research and experience. Additionally, programs contained support that varied in their degree of depth, that is, in how thoroughly they developed ideas and detailed connections among them. Excerpts demonstrating this range of support for three of the most commonly coded criteria are presented and discussed below.

With regard to support for teachers' subject matter knowledge, one program provided over a page of detailed, relevant information pertaining to the characteristics of a population, types of growth curves, and the effects of population size, carrying capacity, and growth rates (P1, p. 177). This educative support provided teachers with relevant, in-depth support by thoroughly elaborating upon the core concepts in the student text. In contrast, the following excerpt on factors impacting population size provided teachers with less comprehensive support:

> Science Background: Animal population size can be influenced by amount of food and space available. Natural populations cannot increase forever; population size is also controlled by environmental and biological factors. Animals immigrating to one area are emigrating from another area. A chief factor influencing the size of a plant population is the amount to daily sunlight and the space available in which roots can grow and spread. (P2, p. 632)

This passage shows that in supporting teachers' subject matter knowledge, some materials provided only brief snippets of support and lists of disconnected facts. Other subject matter knowledge supports for teachers not only lacked depth but were also unrelated to key ideas in the student text. Therefore, even though support for teachers' subject matter knowledge was the most frequent type of support in the materials, it varied in its degree of depth and relevance.

Other examples illustrating the variation in quality of support are drawn from supports designed to help teachers attend to students' likely ideas about science. Many materials helped teachers identify their students' ideas by alerting them to common misconceptions. Though some misconceptions were related to central concepts in the text, others were not, including, "Students may think that an environmentalist is the same as an ecologist" (P4, p. 40), and "A popularly held misconception is that large groups of lemmings, a small arctic mammal, periodically march into the ocean in mass suicides, thus reducing their large population" (P4, p. 76).

In addition to providing a range of relevant support for identifying their students' ideas, curriculum materials contained a range of support for dealing with those ideas, varying in their degree of depth and pedagogically helpfulness. Most programs instructed teachers to simply tell students the correct scientific answer—an approach not likely to foster student understanding (Bransford, Brown, & Cocking, 1999): "Misconception. The following statement is often heard from students. 'Humans evolved from apes.' Advise students that evolutionary evidence supports the theory that humans and apes evolved from a common early ancestor" (P2, p. 605). This excerpt shows that some supports were extremely limited in depth and questionable in effectiveness, providing minimal guidance for teachers.

In contrast, some materials included more comprehensive and helpful supports by exploring worthwhile ideas in depth. For example, the excerpt below includes a more thorough discussion of how a teacher might deal with the same misconception described above:

> Revealing Misconceptions. "If humans evolved from apes, why are there still apes alive today?" is a question often posed by students. The question represents a common misconception that students have about human evolution.
>
> Uncover the Misconception. Explain that humans evolved from ancestors of apes, which were neither humans nor apes, and the common ancestor probably lived during the Miocene.
>
> Demonstrate the Concept. Use an example from the previous chapter to explain the concept of common ancestry. You might use an example from the Galapagos Islands, or divergent evolution of the honeycreepers in Hawaii.
>
> Assess New Knowledge. Ask students to suggest other examples of species that are closely related and what their common ancestor may have been. Have them suggest how they might explain this to a friend. (P3, p. 431)

This extensive discussion provides useful guidance about how teachers might foster student learning about evolution, illustrating an example of pedagogically helpful and in-depth support for dealing with students' ideas about science. Additionally, other supports provided opportunities for teachers to help students contrast their ideas with scientifically normative ideas and to think more deeply about their own ideas. The following excerpt highlights such a support:

> Do not reveal this information to the students at any point during the activity. Rather, allow them to form their own explanations and opinions. Even if students express misconceptions about species or other concepts, do not correct their errors outright. Instead, guide them toward a more accurate and complete understanding by asking question such as, How do you know? How can you be sure? or How might you test your idea? (P5 p. 134)

This passage highlights another kind of high quality support for dealing with students' ideas.

Overall, these examples illustrate the range in quality of support found in the curriculum materials. Educative supports varied in their degree of relevance, pedagogical helpfulness, and depth, impacting the opportunities that teachers had to develop a more complete understanding of a strategy or topic and to integrate their ideas.

Range of Explicit, Embedded, and Integrated Support

In addition to the dimensions discussed above, the educative supports also varied along other dimensions related to their location and format in the materials. The supports differed in their degree of explicitness, that is, in terms of how clearly the materials specified where supports could be found in the materials and what types of teacher knowledge were targeted in each support. They also varied in how embedded they were, that is, the extent to which supports were assimilated into the student text. Additionally, the materials contained support that differed in how integrated they were, that is, the extent to which supports integrated multiple types of teacher knowledge. Trends across materials with regard to these three dimensions are described in Table 6 and discussed below.

Table 6
Degree of Explicitness, Embeddedness, and Integration in Education Supports Across Programs

Characteristics of Materials	P2, P3, P4, P6, P8 (Teacher Editions of Textbook)	P1, P7 (Teacher Guides)	P5 (Teacher Guide)
Explicitness of location and types of supports	Yes (expect P6)	Mixed	No
Embeddedness of supports in student text	No	Yes	Yes
Integration of multiple knowledge types within supports	No	Yes	Mixed

The majority of the programs were similar in their location and appearance of supports (P2, P3, P4, P6, P8). These materials typically indicated where teacher-learning supports were located in the materials and what types of support were provided (P2, P3, P4, P8). For example, educative supports were found in designated sections containing specific headings specifying the type of support provided. Headings included Misconceptions, Teacher Background Information, Prior Knowledge, Things to Watch For, and Use Visuals. In terms of embeddedness, the materials were formatted with the student text in one place and the supports in another – close by but not organically embedded in the student text. Additionally, with regard to knowledge integration, these particular materials typically did not integrate multiple types of teacher knowledge within the educative supports. In other words, supports frequently targeted only one aspect of teacher knowledge (e.g., knowledge for using instructional representations) at any given time. Materials formatted as teacher editions of textbooks with wraparound text typically embodied these characteristics.

In contrast to the format described above, some curricular programs explicitly stated which sections were intended to support teacher learning but frequently did not specify what type(s) of knowledge was targeted in each support (P1, P7). For example, most educative supports were found in specific sections containing general headings such as Instructional Notes and Teaching Strategy. With regard to embeddedness, the teacher materials tended to provide descriptions of student activities (not the student text, itself), and within those descriptions, embed supports for teachers, as appropriate. In terms of integration, the educative supports often targeted multiple types of knowledge among and within sections with the same heading. The following excerpt highlights this design set-up:

> Science Background: The last question [Which do you think might come "first," the structure or the function?] is designed to be thought-provoking and is somewhat specious: there is no ordered or determined designing of a structure to fit a function in the natural world. There is often a misconception among students that "polar bears have heavy coats because they live where it is cold." Structures have evolved from many small variations, and those variations may enable the organism to be suited to the environment and survive. Evolution is not predetermined to a needed function or end. In fact, the fossil record is full of organisms that had exquisite structures but no longer exist. These important concepts must be clear to students in order for them to understand why it may appear that there has been a deliberate match between a structure and its function. This is developed further in the reading "Evolutionary Theory: Past and Present" and in the activity "Going with the Flow," both of which are in the Student Manual. (P7a, p. 81)

This excerpt shows how one section integrated a variety of educative supports for teachers, including a rationale for using a particular question (4A), teacher background information (9B), information about a common misconception (3B), ideas for tasks that address the misconception (3C), and a rationale for having students engage in the reading and activity (1A). Overall, materials formatted as teacher guides typically possessed this combination of characteristics.

Finally, the format of the educative supports in the last remaining curricular program was different from the rest (P5). With regard to explicitness, this program provided few indications about where educative supports could be found in the materials, and subsequently, few indications about what types of supports were provided. Aside from bolding the text to denote information for teachers, this program did not systematically clarify when the materials were going beyond baseline features to provide teachers with rationales and implementation guidance. In terms of embeddedness, this curricular program included excerpts from the student text (e.g., directions for activities, lists of discussion questions), and within those excerpts, embedded relevant supports for teachers. The following example illustrates this feature by embedding an educative support within a list of discussion questions for students. It reads,

> 3. Are the patterns that you chose to describe evidence, or were there inferences involved in finding and describing the patterns?
>
> **This question revisits the students' understandings of evidence and inference. The patterns themselves are observed directly from the evidence presented by the model. The timeline model is based on the evidence that were gathered by scientists who determined the timing of the events. The exact timing given for the events are inferences that are based on collections of evidence.**
>
> 4. What did the timeline (a model) help you understand… (P5, p. 68)

Here, a rationale for using a particular question with students is embedded within the activity itself, rather than separate from the student text. With regard to integration, these materials sometimes provided support that targeted multiple types of teacher knowledge, but in other cases, embedded support fostering only one aspect of teacher knowledge. This program was formatted as a teacher guide.

Overall, the materials in this analysis contained a range of explicit, embedded, and integrated support. Some materials specified certain sections for educative supports while others provided no indication about where supports could be found. Materials also varied in how clearly they indicated the type of support that was provided, using descriptive headings, general headings, or no labels at all. Additionally, some curricular programs embedded supports within descriptions of activities while others placed supports next to verbatim sections of student text. Finally, materials integrated different types of teacher knowledge to varying degrees, ranging from thorough to little integration within supports.

In sum, the results in this section show that the quantitative results were not the only indicator of the quality of the curriculum materials in terms of how educative they were for teachers. Patterns in the data showed that the educative supports exhibited a range of relevant, pedagogically helpful, and in-depth support for teachers and varied in their location and appearance in the materials. These ranges show that some educative features provided more support for teacher learning than others.

Discussion and Implications

The results of this study emphasize the need to design better science curriculum materials for teachers in order to help teachers be more effective in fostering a deep understanding of science among their students. The findings described in this paper highlight the existing strengths, limitations, and gaps in teacher learning supports in current curriculum materials and provide insights into the development of more effective educative supports for teachers.

Results indicate that the high school biology curricular programs reviewed in this study included a variety of educative supports but were not likely to support teacher learning in all three domains of teacher knowledge. Materials tended to provide abundant support for teachers' subject matter knowledge and aspects of teachers' PCK for science topics, such as helping teachers attend to students' likely ideas about science. However, they tended to include far less support for other components of PCK for science topics, including support for helping teachers engage students in scientific phenomena and instructional representations, as well as support for all categories of PCK for scientific inquiry. This latter finding is unsurprising since most of the textbooks provided students with few opportunities to learn science through inquiry, and consequently, provided teachers with few opportunities to develop their understanding of how to teach science in reform-oriented ways. Recent reviews of curricular programs have identified similar shortcomings in the baseline features of middle school and high school science materials, showing that these programs tend to provide inadequate opportunities for students to learn key scientific ideas (AAAS, 2005; Kesidou & Roseman, 2002).

Despite the limited support for specific aspects of teacher knowledge, this finding must be considered in light of the fact that the curriculum materials examined in this study were prepared without the benefit of the design heuristics that guided our analysis (Davis & Krajcik, 2005). It is hoped that this study can positively impact the design of future curriculum materials by highlighting areas of teacher knowledge in need of support. To better meet the recommendations of the standards (NRC, 1996, 2000), materials need to include more inquiry-oriented activities for students, and subsequently, more support for teachers to help them understand the importance of specific inquiry practices and how to effectively use and modify them in their own classroom instruction. Curricular programs also need to include more supports for PCK for topics, specifically in helping teachers use specific scientific phenomena and instructional representations in their practice.

In addition to examining the frequency of supports across the different teacher knowledge domains, the frequency of the two main forms of support was also examined. The results show that the materials tended to have more than twice as much implementation guidance support than rationales. Across the corpus analyzed, the materials provided more support for *how* teachers could use or adapt instructional approaches than for *why* teachers should use these approaches. This finding is consistent with other studies that show that curriculum materials need to provide more opportunities for teachers to examine assumptions and agendas underlying particular instructional approaches in the materials in order to make sense of activities inspired by reform recommendations (Remillard, 2000). However, the ideal proportion of rationale to implementation guidance support is unknown. A given activity may require only one instance of rationale to justify and explicate its inclusion but may require multiple instances of implementation guidance support to understand how to use and adapt the same activity. Therefore, these findings emphasize the need for curriculum designers to consistently include both forms of support in the design of materials, rather than advocate a fixed ratio of support.

With regard to the quality of support, the curriculum materials exhibited a range in terms of their degree of relevance to the core concepts in the student materials, pedagogical helpfulness, and depth and comprehensiveness. This wide range of support limited opportunities for teacher learning. Other curriculum reviews have found a similar trend in quality of supports for student learning as well as some aspects of teacher learning, showing that science materials frequently provided students and teachers with support unrelated to core concepts as well as piecemeal and fragmented support (AAAS, 2005; Kesidou & Roseman, 2002). In order to better foster teachers' understanding of reform-oriented practices, curriculum developers need to avoid sacrificing understanding for brevity. Instead, curriculum materials need to include strong examples of support that are relevant, pedagogically useful, and sufficiently in depth in order to provide teachers with rich, substantive support that is related to core scientific concepts.

The location and appearance of the educative supports varied as well across the set of curriculum materials. The supports differed in terms of the explicitness of their location in the materials and the types of teacher knowledge targeted within each support. Signaling to teachers when text is intended to support their learning and what kinds of information is included in such text may help teachers recognize potential learning opportunities for themselves. Additionally, making explicit the location and types of support in the materials may help curriculum developers be cognizant of the need to be systematic in providing similar types of support throughout the materials. Consistently providing similar types of support may also help teachers become familiar with the kinds of support embedded in the materials and to learn how to navigate through the materials to find particular kinds of support and guidance, as they need it.

The supports in the materials also varied in terms of how embedded they were within student activities and tasks. Materials designed as teacher guides tended to embed supports within the actual steps and descriptions of the activities themselves while materials formatted as teacher editions of textbooks typically placed supports alongside the student text. By embedding supports in the middle of the baseline features rather than off to the side, teachers may be provided with "just-in-time" support, where they are able to receive the support they want when they need it. For example, by embedding support directly after a particular step in an activity or after a specific discussion question, teachers are able to access immediately relevant information when they are enacting that step or question in class. Other researchers have also demonstrated the usefulness of providing learners with guidance on demand (Bell & Davis, 2000; Shrader & Gomez, 1999). Therefore, it may be worthwhile for curriculum developers to consider this approach to embedding guidance in curriculum materials in order to foster teachers' learning about reform-oriented practices (Davis, Smithey, & Petish, 2004).

Additionally, the curriculum materials integrated support for different types of teacher knowledge to varying degrees, ranging from thorough to little integration within supports. Integrating guidance for multiple types of knowledge within the same support may provide opportunities for different types of supports to work synergistically to foster the development of teachers' knowledge about a particular instructional approach, activity, or topic. Helping learners not only add ideas to their knowledge base but also to integrate their knowledge by creating new connections among ideas is essential for promoting learning (Linn, Eylon, & Davis, 2004; Linn & Hsi, 2000). Therefore, curriculum developers should consider productive ways of supporting multiple types of teacher knowledge within the same support.

These recommendations for the design of educative supports, though useful, must be regarded as tentative because research studies have just begun to investigate the effects of the structural components of curricular features on teacher learning (Love & Pimm, 1996; Remillard, 2002). In order to increase the field's understanding in this area, further research is needed in order to understand how these curricular features that, although not directly related to science content, may impact teacher learning (Remillard, 2005). Investigating text characteristics is essential in order to understand how teachers use and learn from curriculum materials.

In a comparison of the eight science programs (Beyer et al., 2006), P5 and P7 consistently provided more support for teachers than any other material, including the commercially successful texts. The qualitative analyses revealed that many of these supports were in-depth, pedagogically helpful, and relevant for teachers, as illustrated with examples throughout this paper. These findings are similar to Project 2061's recent evaluation of high school biology textbooks, which found that the same two programs ranked highest, according to their evaluation criteria (AAAS, 2005; see Average of Ratings for Four Topics table). Even though P5 and P7 had a small market share (<2% in 2000; Weiss et al., 2001) and have room for improvement (AAAS, 2005), these NSF-funded materials can serve as exemplars to inform the design of curriculum materials (St. John, 2002, as cited in National Research Council, 2004) and can guide textbook adoption decisions made by local school districts.

In conjunction with these recommendations for the design of educative curriculum materials, two fundamental tensions need to be considered. First, curriculum developers face the tension of providing support for a diverse array of teachers (Davis & Krajcik, 2005). Teachers with varying amounts of teaching experience and familiarity with inquiry teaching may require different types and degrees of support. For example, teachers with extended experience teaching the same topic and in-depth knowledge of reform-oriented teaching practices may need less guidance in interpreting students' responses to particular questions or in using particular instructional representations that they have used in the past. Second, curriculum developers also face the tension of providing teachers with sufficient support yet not inundating them with too much information (Davis & Krajcik, 2005). Determining the appropriate amount of guidance is important because teachers often do not have time to read everything in the curriculum materials. Additionally, teachers need room to draw upon their own personal resources to make productive changes and local adaptations to curriculum materials (Barab & Luehmann, 2003; Brown & Edelson, 2003). These tensions may be amenable to empirical research seeking to establish rules of thumb that can guide these decisions. Investigating the affordances of electronic media may also begin to address these tensions, by enabling teachers to select only the supports they need (Fishman & Davis, 2006).

Additionally, educative curriculum materials cannot single-handedly change the status quo in science classrooms. Embedding educative materials within a professional development program may be more effective at helping teachers develop expertise in science teaching (Ball & Cohen, 1996; Fishman, Marx, Best, & Tal, 2003). Complementing curriculum materials with additional forms of support such as face-to-face summer workshops, online discussion boards, and ongoing professional development during the school year may help facilitate teacher change (Putnam & Borko, 2000; Schneider & Krajcik, 2002). The availability of these professional development opportunities may also help address the fundamental tension of determining how much guidance to provide teachers in curriculum materials.

Finally, this study highlights the need to develop a more comprehensive procedure for evaluating the potential of existing curriculum materials for promoting teacher learning. First, support for a wider range of knowledge types, rather than just the three teacher knowledge domains examined in this study, need to be included in an evaluation procedure. Learning goals for science teachers identified as important in the research literature and in the learning goals put forth by the National Research Council (1996) and the National Science Teaching Association (2003) may help identify the components of teacher knowledge that are in need of support. For example, additional criteria may be needed to evaluate support for other crucial aspects of teachers' PCK for science teaching, including their understanding of science curricula and assessment practices (Magnusson et al., 1999; NRC, 1996; NSTA, 2003). Second, a revised procedure is needed in order to describe both the quantity *and* quality of teacher learning supports. In addition to identifying categories of support and specific criteria for each category, as done in this study, indicators also need to be specified in order to judge how well materials meet each criterion, and a rating system is needed to determine which characteristics need to be met to achieve a particular rating. In these ways, additional research is needed in order to inform the development of a more refined evaluation procedure and to rigorously test for reliability and validity of the instrument.

References

American Association for the Advancement of Science. (1993). *Benchmarks for science literacy.* New York: Oxford University Press.

American Association for the Advancement of Science. (2005). *High school biology textbooks: A benchmarks-based evaluation.* Retrieved February, 2, 2007, from http://www.project2061.org/publications/textbook/hsbio/report/browse.htm.

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

Ball, D. L., & Feiman-Nemser, S. (1988). Using textbooks and teachers' guides: A dilemma for beginning teachers and teacher educators. *Curriculum Inquiry, 18*, 401 – 423.

Barab, S.A. & Luehmann, A.L. (2003). Building sustainable science curriculum: Acknowledging and accommodating local adaptation. *Science Education, 87*, 454-467.

Bell, P., & Davis, E. A. (2000). Designing Mildred: Scaffolding students' reflection and argumentation using a cognitive software guide. In B. Fishman & S. O'Connor-Divelbiss (Eds.), *International Conference for the Learning Sciences 2000*. Mahwah, NJ: Lawrence Erlbaum Associates.

Beyer, C.J., Delgado, C., Davis, E.A., & Krajcik, J.S. (2006). *Investigating high school biology texts as educative curriculum materials: Curriculum review process*. Ann Arbor, MI: University of Michigan.

Biggs, A., Hagins, W. C., Kapicka, C., Lundgren, L., Rillero, P., Tallman, K.G., Zike, D., & National Geographic Society. (2005). *Biology: The dynamics of life*. New York: Glencoe/McGraw-Hill.

Biggs, A., Kaskel, A., Lundgren, L., & Mathieu, D. (2003). *Biology: Living systems*. New York: Glencoe/McGraw-Hill.

Biological Sciences Curriculum Study (BSCS). (2006a). BSCS *Biology: A human approach* (3rd ed.). Dubuque, IA: Kendall/Hunt Publishing Company.

Biological Sciences Curriculum Study (BSCS). (2006b). BSCS *Biology: An ecological approach* (10th ed.). Dubuque, IA: Kendall/Hunt Publishing Company.

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

Bransford, J. D., Brown, A. L., & Cocking, R. R. (Eds.). (1999). *How people learn: Brain, mind, experience, and school*. Washington, DC: National Academy Press.

Brown, M., & Edelson, D. (2003). *Teaching as design: Can we better understand the ways in which teachers use materials so we can better design materials to support their changes in practice?* (Design Brief). Evanston, IL: Center for Learning Technologies in Urban Schools.

Collopy, R. (2003). Curriculum materials as a professional development tool: How a mathematics textbook affected two teachers' learning. *The Elementary School Journal, 103*(3), 227–311.

Davis, E. A., & Krajcik, J. (2005). Designing educative curriculum materials to promote teacher learning. *Educational Researcher, 34*(3), 3-14.

Davis, E. A., Smithey, J., & Petish, D. (2004). Designing an online learning environment for new elementary science teachers: Supports for learning to teach. In Y. B. Kafai, W. A. Sandoval, N. Enyedy, A. S. Nixon & F. Herrera (Eds.), *Proceedings of the 6th International Conference of the Learning Sciences, ICLS2004*. Mahwah, NJ: Lawrence Erlbaum Assoc.

Education Development Center, Inc. (EDC). (1998). *Insights in biology* (*The matter of life* and *What on earth?* modules). Dubuque, IA: Kendall/Hunt Publishing Company.

Fishman, B., & Davis, E. A. (2006). Teacher learning research and the learning sciences. In R. K. Sawyer (Ed.), *Cambridge Handbook of the Learning Sciences* (pp. 535-555). New York: Cambridge University Press.

Fishman, B., Marx, R., Best, S., & Tal, R. (2003). Linking teacher and student learning to improve professional development in systemic reform. *Teaching and Teacher Education, 19*(6), 643-658.

Grossman, P., & Thompson, C. (2004). *Curriculum materials: Scaffolds for teacher learning?* (No. R-04-1). Seattle: Center for the Study of Teaching and Policy.

Heaton, R. M. (2000). *Teaching mathematics to the new standards: Relearning the dance*. New York: Teachers College Press.

Kaskel, A., Hummer, P.J., & Daniel, L. (2003). *Biology: An everyday experience.* New York: Glencoe/McGraw-Hill.

Kesidou, S., & Roseman, J. E. (2002). How well do middle school science programs measure up? Findings from Project 2061's curriculum review. *Journal of Research in Science Teaching*, 39(6), 522-549.

Krajcik, J., Blumenfeld, P., Marx, R., & Soloway, E. (2000). Instructional, curricular, and technological supports for inquiry in science classrooms. In J. Minstrell & E. Van Zee (Eds.), *Inquiring into inquiry learning and teaching in science* (pp. 283-315). Washington, DC: American Association for the Advancement of Science.

Krajcik, J., Mamlok, R., & Hug, B. (2001). Modern content and the enterprise of science: Science education in the twentieth century. In L. Corno (Ed.), *Education across a century: the centennial volume* (pp. 205-231). Chicago: NSSE.

Leonard, W. H., & Penick, J. E. (2003). *Biology: A community context*. New York: Glencoe/McGraw-Hill.

Linn, M. C., Davis, E. A., & Eylon, B.-S. (2004). The scaffolded knowledge integration framework for instruction. In M. C. Linn, E. A. Davis & P. Bell (Eds.), *Internet Environments for Science Education* (pp. 47-72). Mahwah, NJ: Lawrence Erlbaum Associates.

Linn, M. C., & Hsi, S. (2000). *Computers, teachers, and peers: Science learning partners*. Hillsdale, NJ: Lawrence Erlbaum Associates.

Lortie, D. (1975). *Schoolteacher: A sociological study*. Chicago: University of Chicago Press. Chapter 3: The limits of socialization.

Love, E., & Pimm, D. (1996). "This is so": A text on texts. In A.J. Bishop, K. Clements, C. Keitel, J. Kilpatrick, & C. Laborde (Eds.), *International handbook of mathematics, Part 1* (pp. 371-409). Boston: Kluwer Academic Publishing.

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

Marx, R. W., Blumenfeld, P. C., Krajcik, J. S. & Soloway, E. (1997). Enacting project-based science. *The Elementary School Journal. 97*(4). 341-358.

McDiarmid, G., Ball, D., & Anderson, C. (1989). Why staying one chapter ahead doesn't really work: Subject-specific pedagogy. In M. C. Reynold (Ed.), *Knowledge base for the beginning teacher.* New York: Pergamon.

Miller, K. R., & J. Levine. (2006). *Biology*. Upper Saddle River, NJ: Prentice Hall.

National Research Council. (1996). *National Science Education Standards.* Washington, D.C. National Academy Press.

National Research Council. (2000). *Inquiry and the National Science Education Standards*. Washington, DC: National Academy Press.

National Research Council. (2004). *On evaluating curricular effectiveness: Judging the quality of K-12 mathematics evaluations.* Washington, DC: National Academy Press.

National Science Teachers Association (2003). *Standards for science teacher preparation.* Washington, DC: National Science Teachers Association.

Putnam, R., & Borko, H. (2000). What do new views of knowledge and thinking have to say about research on teacher learning? *Educational Researcher, 29*(1), 4-15.

Remillard, J. T. (2000). Can curriculum materials support teachers' learning? Two fourth-grade teachers' use of a new mathematics text. *The Elementary School Journal, 100*(4), 331-350.

Remillard, J. T. (2002, April). *Modes of engagement: Toward understanding teachers' transactions with unfamiliar curriculum resources*. Paper presented at the annual meeting of the American Educational Research Association, New Orleans.

Remillard, J. T. (2005). Examining key concepts in research on teachers' use of mathematics curricula. *Review of Educational Research, 75*(2), 211-246.

Roehrig, G.H. & Luft, J.A. (2004). Constraints experienced by beginning secondary science teachers in implementing scientific inquiry lessons. *International Journal of Science Education, 26*(1), 3-24).

Schneider, R. (2006). Supporting science teacher thinking through curriculum materials. In S.A. Barab, K.E. Hay, & D.T. Hickey (Eds.), *Proceeding of the Seventh International Conference of the Learning Sciences,* (pp. 674-680). Mahwah, NJ: Lawrence Erlbaum Associates.

Schneider, R., & Krajcik, J. (2002). Supporting science teacher learning: The role of educative curriculum materials. *Journal of Science Teacher Education, 13*(3), 221-245.

Schneider, R., Krajcik, J. & Blumenfeld, P. (2005). Enacting reform-based science materials: The range of teacher enactments in reform classrooms. *Journal of Research in Science Teaching, 42*(3), 283-312.

Schwab, J. (1964). Structure of the disciplines: Meanings and significances. In G. W. Ford & L. Pugno (Eds.), *The structure of knowledge and the curriculum*. Chicago: Rand McNally.

Shrader, G., & Gomez, L. (1999). Design research for the Living Curriculum. In C. Hoadley & J. Roschelle (Eds.), *Computer Support for Collaborative Learning '99* (pp. 527-537). Palo Alto, CA: CSCL.

Shulman, L.S. (1986). Those who understand: Knowledge growth in teaching. *Educational Researcher, 15*(5), 4-14.

Stake, R.E., & Easley, J.A. (1978). *Case studies in science education* (Vol. 2). Washington, D.C.: U.S. Government Printing Office. (No. 038-000-00376-3)

Wang, J., & Paine, L. (2003). Learning to teach with mandated curriculum and public examination of teaching as contexts. *Teaching and Teacher Education, 19(1),* 75-94.

Weiss, I.R., Banilower, E. R.,, McMahon, K. C., & Smith, P. S. (2001). *Report of the 2000 National Survey of Science and Mathematics Education*. Chapel-Hill, NC: Horizon Research, Inc. Retrieved Jan. 12, 2007, from http://2000survey.horizon-research.com/reports/status/complete.pdf

Welch, W. W. (1979). Twenty years of science curriculum development: A look back. *Review of Research in Education, 7,* 282-308.

Windschitl, M. (2002). Inquiry projects in science teacher education: What can investigative experiences reveal about teacher thinking and eventual classroom practice? *Science Education, 87*(1), 112-143.

Zembal-Saul, C. & Dana, T. M. (2000). Exploring the nature, sources, and development of pedagogical content knowledge for supporting children's scientific inquiry (PCK-SI). A paper presented at the annual meeting of the National Association for Research in Science Teaching, New Orleans, LA.

Appendix A

Programs Reviewed

P1: Leonard, W. H., & Penick, J. E. (2003). *Biology: A community context*. New York: Glencoe/McGraw-Hill. [NSF-funded]

P2: Kaskel, A., Hummer, P.J., & Daniel, L. (2003). *Biology: An everyday experience.* New York: Glencoe/McGraw-Hill.

P3: Biggs, A., Hagins, W. C., Kapicka, C., Lundgren, L., Rillero, P., Tallman, K.G., Zike, D., & National Geographic Society. (2005). *Biology: The dynamics of life*. New York: Glencoe/McGraw-Hill.

P4: Biggs, A., Kaskel, A., Lundgren, L., & Mathieu, D. (2003). *Biology: Living systems*. New York: Glencoe/McGraw-Hill.

P5: Biological Sciences Curriculum Study (BSCS). (2006). BSCS *Biology: A human approach* (3rd ed.). Dubuque, IA: Kendall/Hunt Publishing Company. [NSF-funded]

P6: Biological Sciences Curriculum Study (BSCS). (2006). BSCS *Biology: An ecological approach* (10th ed.). Dubuque, IA: Kendall/Hunt Publishing Company. [NSF-funded]

P7: Education Development Center, Inc. (1998). *Insights in biology*. Dubuque, IA: Kendall/Hunt Publishing Company. [NSF-funded] (P7a: *What on earth?* module; P7b: *The matter of life* module)

P8: Miller, K. R., & J. Levine. (2006). *Biology*. Upper Saddle River, NJ: Prentice Hall.

Appendix B

Analysis Criteria

The evaluation procedure used in this study consists of the following criteria dealing with two main forms of support: rationale and implementation guidance. These criteria are organized into nine categories, which are further organized into support for three teacher knowledge domains. These criteria (excluding the baseline features) were used to determine the extent to which materials were likely to promote teacher learning.

Support for PCK for Topics

Category/Criteria	Form of Support
1. Support Teachers in Engaging Students with Topic-Specific Scientific Phenomena	
Provide physical (and vicarious) experiences for students	*Baseline Feature*
A. Explain why particular experiences are appropriate.	Rationale
B. Help teachers adapt and use particular experiences with their students.	Guidance
C. Warn of potential pitfalls with specific physical experiences.	Guidance
D. Help teachers think about productive sequences for experiences.	Guidance
2. Support Teachers in Using Scientific Instructional Representations	
Provide appropriate instructional representations of scientific phenomena	*Baseline Feature*
A. Explain why particular representations are appropriate.	Rationale
B. Help teachers adapt and use particular representations with students.	Guidance
3. Support Teachers in Anticipating and Dealing with Students' Ideas About Science	
A. Explain why attending to students' ideas is important.	Rationale
B. Help teachers identify likely student ideas within a topic.	Guidance
C. Help teachers deal with their students' ideas in their teaching.	Guidance

Support for PCK for Inquiry

Category/Criteria	Type of Support
4. Support Teachers in Engaging Students in Questions	
Provide driving questions to frame unit and focus questions for discussion.	*Baseline Feature*
A. Explain why particular questions are appropriate.	Rationale
B. Help teachers adapt and use questions.	Guidance
C. Help teachers engage students in asking/answering their own questions.	Guidance
5. Support Teachers in Engaging Students With Collecting and Analyzing Data	
Suggest approaches to help students collect, compile, and understand data.	*Baseline Feature*
A. Explain why specific approaches for collection/analysis are appropriate.	Rationale
B. Explain why evidence is essential to scientific inquiry.	Rationale
C. Help teachers adapt and use approaches for collecting & analyzing data.	Guidance
D. Help teachers adapt and use particular approaches for collecting and analyzing data across multiple topic areas.	Guidance
6. Support Teachers in Engaging Students in Designing Investigations	
Provide opportunities for students to design their own investigations.	*Baseline Feature*
A. Explain why having students design their investigations is important.	Rationale

B. Provide guidance for how teachers can support students in designing their own investigations.	Guidance
7. Support Teachers in Engaging Students in Making Explanations Based on Evidence	
Suggest approaches to help students make explanations based on evidence.	*Baseline Feature*
A. Explain why specific explanation-building approaches are appropriate.	Rationale
B. Explain why engaging students in explanations is essential to inquiry.	Rationale
C. Help teachers adapt and use particular approaches for constructing evidence-based explanations with their students.	Guidance
8. Support Teachers in Promoting Scientific Communication	
Provide teachers with approaches for promoting science communication.	*Baseline Feature*
A. Explain why specific communication approaches are appropriate.	Rationale
B. Help teachers adapt and use particular communication approaches.	Guidance

Support for Subject Matter Knowledge

Category/Criteria	Type of Support
9. Support Teachers in the Development of Subject Matter Knowledge	
Help teachers develop factual and conceptual science knowledge.	*Baseline Feature*
A. Explain why strong subject matter knowledge is important for teaching.	Rationale
B. Present science content information that is beyond the level of understanding required by students.	Other Educative Feature