Designing Educative Curriculum Materials to Promote Teacher Learning

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Curriculum materials for Grades K–12 that are intended to promote teacher learning in addition to student learning have come to be called *educative curriculum materials.* How can K–12 curriculum materials be designed to best promote teacher learning? What might teacher learning with educative curriculum materials look like? The authors present a set of design heuristics for educative curriculum materials to further the principled design of these materials. They build from ideas about teacher learning and organize the heuristics around important parts of a teacher's knowledge base: subject matter knowledge, pedagogical content knowledge for topics, and pedagogical content knowledge for disciplinary practices. These heuristics provide a context for a theoretically oriented discussion of how features of educative curriculum materials may promote teacher learning, by serving as cognitive tools that are situated in teachers' practice. The authors explore challenges in the design of educative curriculum materials, such as the tension between providing guidance and choice.

Teachers are expected to teach meaningful content that helps students to meet learning goals in the context of authentic activities, while addressing the needs of diverse learners and ensuring that all students are successful. To help teachers meet these high expectations and thus promote educational reform, K–12 curriculum materials might be designed to promote teacher learning as well as student learning—a notion suggested by Ball and Cohen (1996) in *Educational Researcher* almost a decade ago and by Bruner (1960) even earlier. We present design heuristics for such curriculum materials to guide designers and to provide a context for discussing how curriculum materials might support teacher learning. The heuristics are grounded in science teaching but are useful in considering the design of curriculum materials across fields.

As we elaborate below, *teacher learning* involves developing and integrating one's knowledge base about content, teaching, and learning; becoming able to apply that knowledge in real time to make instructional decisions; participating in the discourse of teaching; and becoming enculturated into (and engaging in) a range of teacher practices. Teacher learning is situated in teachers' practice—including classroom instruction but also planning, lesson modification, assessment, collaboration with colleagues, and communication with parents. K–12 curriculum materials that are intended to promote teacher learning have come to be called *educative curriculum materials*. The word educative refers to teachers as learners (K–12 curriculum materials are assumed to be educative for students) and does not imply a theoretical stance toward the nature of education as a whole.

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Educative curriculum materials should help to increase teachers' knowledge in specific instances of instructional decision making but also help them develop more general knowledge that they can apply flexibly in new situations. Such a focus distinguishes educative curriculum materials from typical teachers' guides, which include supports for teaching strategies but not for teacher learning, and from typical K–12 curriculum materials more generally, which aim mainly at promoting student learning. For example, an elementary science curriculum might recommend having each group of students run an experiment several times, without explaining why doing so is important (i.e., to produce better, more reliable results). Testing the theoretical claim that educative curriculum materials can promote changes in teachers' knowledge and practice requires the principled development of such materials.

Before worrying about adding educative elements to curriculum materials, designers must ensure that the "base" curriculum materials are accurate, complete, and coherent in terms of content and effective in terms of pedagogy—with good representations of the content, a clear purpose for learning it, and multiple opportunities for students to explain their ideas. Reviews of typical textbooks, however, have identified serious problems along both of these dimensions (e.g., Hubisz, 2003; Kesidou & Roseman, 2002). Engaging in serious formative evaluation can help to redress this problem. Once this baseline condition is met, then it makes sense to attend to issues of teacher learning through the curriculum.

How teachers use and learn from K–12 curriculum materials depends, at a fundamental level, on interactions among the three components involved in any learner's interaction with text: the reader, the text, and the context (Rumelhart, 1994). Characteristics of the text that matter include how the text is structured (e.g., whether the first sentence of a paragraph is the most important) and how considerate it is (e.g., whether it builds on a reader's prior knowledge and experience) (Armbruster & Anderson, 1985). A reader's motivation, interest, prior knowledge, and ability to be strategic in her reading all influence how she interacts with a text, as do contextual factors such as how much time she has available for the reading task.

Specifically, teachers' use of and learning from text-based curriculum materials depend not only on the characteristics of the curriculum materials but also on the type of teaching activity in which the teacher is engaged, the teacher's persistence or lack of persistence in reading the materials over time, what the teacher chooses to read or ignore, the teacher's own knowledge and beliefs (e.g., about content, learners, learning, teaching, and curriculum materials), how those beliefs are aligned with the goals of the curriculum, and the teacher's disposition toward reflective practice (Collopy, 2003; Remillard, 1999; Schneider & Krajcik, 2002). These factors interact in a complex and dynamic relationship (Lloyd, 1999) as teachers interpret the curriculum materials and shape the enacted curriculum (Clandinin & Connelly, 1991).

Furthermore, teacher learning will best be promoted by a set of complementary approaches, not by a single one. For example, a face-to-face summer workshop and online discussion would complement the learning promoted by educative curriculum materials by providing the social supports crucial to teacher learning (Putnam & Borko, 2000). Realistically, however, teachers' use of curriculum materials in the near term probably will occur without such important support. Considering how to make the curriculum materials educative, then, is an important step toward promoting teacher learning given the realities of schools (Collopy, 2003). At least, such materials will promote learning among some teachers and may promote the development of a disposition toward reflection among others. In a best-case scenario—with curriculum materials accompanied by other continuing professional development—incorporating educative elements into the materials should increase the learning outcomes over and above improvements resulting from the professional development alone. We emphasize that educative curriculum materials, like any educational innovation, cannot serve as a panacea. Nonetheless, these materials provide one form of intervention likely to support some teachers in very important ways.

Goals and Structure of the Article

Given this complex constellation of factors, as well as the relative recency of the resurgence of interest in educative curriculum materials, it is not surprising that the researchers do not yet know much about how best to design these materials. To address the problem, we ask, *How can K–12 curriculum materials be designed to support teacher learning, and what might teacher learning with educative curriculum materials look like?* We present a set of design heuristics for educative curriculum materials. Our heuristics serve two purposes, which align with our dual goals for this article. First, the heuristics can guide designers of curriculum materials. Second, and perhaps more important, they provide a context for a more theoretically oriented discussion of how particular kinds of educative features might promote teacher learning.

Design of any educational innovation involves iterations of developing, implementing, testing, and refining ideas. Initial designs should be based on theoretical understandings of goals combined with informed intuitions about best practices. Once the initial design approaches are implemented, they are refined on the basis of empirical study (Design-Based Research Collective, 2003). The iterations move designers closer and closer to a principled design. To guide the design of educative curriculum materials, then, we need to ground design heuristics in the specific challenges that teachers face, to help ensure the usefulness of features intended to be educative. Note that we use the term "design heuristics" rather than the more common "design principles." Our recommendations are intended to be useful rules of thumb and not principles, which would imply a level of empirical testing that researchers have not yet undertaken. For similar reasons, we avoid the term "standards." Nonetheless, these design heuristics take us one step closer to the principled design of educative curriculum materials, necessary for this early stage of the research.

To ground our discussion, we discuss teacher learning and describe the knowledge base that teachers need. Next, we present some high-level guidelines that have been set forth in discussions of educative curriculum materials. We then present our design heuristics and discuss how educative features based on them could promote teacher learning. To close, we discuss factors that limit the effectiveness of educative curriculum materials and tensions in their design, and we outline the next steps that we see as critical for researchers interested in these materials and how they promote teacher learning.

Teacher Learning and Teacher Knowledge

Comparing teacher learning with student learning can highlight some of the complexities associated with promoting the former.[1] One fundamental similarity is that the effectiveness of any educational intervention depends on how the opportunity is used by the individual. But, developmentally, teachers are quite different from K–12 students; they also have much greater agency over their learning. Students are expected to attend school, where they should benefit from a coherent set of learning experiences; in contrast, teachers' learning experiences are haphazard after their initial preparation (Wilson & Berne, 1999). Educators' main goal for student learning is development of subject matter knowledge—an understanding of the facts, concepts, theories, structures, practices, and beliefs of the field (Schwab, 1964). Teachers need strong subject matter knowledge but must also develop pedagogical knowledge and pedagogical content knowledge (PCK)—that is, knowledge of how to teach the content (Shulman, 1986). Teachers (like any learners) must also integrate their knowledge (Davis, 2004; Linn, Eylon, & Davis, 2004). They need to make connections between ideas, in addition to adding new ideas about subject-area concepts, instructional approaches, students' likely ideas, or teaching principles. And teachers need to apply their integrated knowledge flexibly to make decisions in real time and in widely varying contexts—for example, applying what they know about fractions to respond to ideas that come up in student discussion (Ball & Bass, 2000). Their real-time decisions affect 20 or more students at a time. Teachers' learning is situated in their daily practice and distributed across individuals as well as across artifacts such as curriculum materials (Putnam & Borko, 2000). As a result, it can be difficult for teachers to connect theory with practice or to extract general rules that can apply across multiple contexts (see Fenstermacher, 1994). Finally, teachers must participate in the discourse of teaching and, more generally, become enculturated into a range of teaching practices (Borko, 2004). In sum, teacher learning, like any learning, has both individual and social aspects (Borko, 2004; Cobb, 1994), and both are crucial in developing expertise. In many ways, promoting teacher learning is even more complex than promoting student learning.

We focus here on teachers' subject matter knowledge and especially PCK, because these present challenges for teachers and represent areas where curriculum materials might achieve the most success in promoting teacher learning and changes in practice (Collopy, 2003; Schneider & Krajcik, 2002). Many scholars have elaborated on and extended Shulman's (1986) notion of PCK (e.g., Ball & Bass, 2000; Wilson, Shulman, & Richert, 1987). Magnusson and colleagues (1999) build on Grossman's (1990) framework to describe PCK as incorporating teachers' topic-specific knowledge about students' ideas and instructional strategies, among other components. For example, a middle school physical science teacher would know that students confuse heat and temperature and would know of and be able to enact strategies for helping them distinguish between the two.

Teachers also need what we call *PCK for disciplinary practices*. Teachers must know how to help students understand the authentic activities of a discipline, the ways knowledge is developed in a particular field, and the beliefs that represent a sophisticated understanding of how the field works. The physical science teacher mentioned above would hold PCK for disciplinary practices that would help him to engage students in the essential features of scientific inquiry (Petish, 2004; Zembal-Saul & Dana, 2000), such as asking and answering scientific questions, experiencing scientific phenomena, developing explanations based on evidence, and communicating and justifying findings (National Research Council, 2000). The teacher's knowledge also would allow him to help students understand the practices themselves. PCK for disciplinary practices in mathematics would be framed around the essential features of inquiry in mathematics, such as developing and evaluating mathematical arguments and communicating mathematical thinking coherently (National Council of Teachers of Mathematics, 1991). Likewise, a history teacher would need to know of and be able to enact instructional strategies to help students, for example, identify important historical questions, differentiate between facts and interpretations, compare competing interpretations, and construct sound historical interpretations based on historical data and contextual knowledge (National Center for History in the Schools, 1996). Elementary teachers typically teach all of these subjects and more and need PCK for disciplinary practices in *many* disciplines.

Across fields, the specific facets of teachers' PCK for disciplinary practices demonstrate similarities as well as differences. Our point is not to argue that there is structural congruence across all subject areas but rather to suggest that expert teachers across subject areas and grade levels have a similar *type* of knowledge beyond those typically identified explicitly. Promoting the development of teachers' PCK for disciplinary practices is crucial in light of current reforms.

The Design of Educative Curriculum Materials: Some High-Level Guidelines

What might K–12 curriculum materials look like if they were designed with the intention of promoting teacher learning? Ball and Cohen (1996) describe some of the roles that curriculum materials could play in promoting teacher learning toward the end of supporting educational reform. Their recommendations are high-level guidelines that are consistent with or, in some cases, provide a framework for the design and research that have since elaborated on their suggestions and illustrated how they play out empirically. In turn, the limited empirical work that has been done suggests some specific areas in which educative curriculum materials can promote teacher learning and, more generally, acts as a proof of concept with regard to the possible positive effects of these materials.

First, educative curriculum materials could help teachers learn how to anticipate and interpret what learners may think about or do in response to instructional activities (Ball & Cohen, 1996; see also Collopy, 2003; Heaton, 2000; Remillard, 2000). Describing why students might hold particular ideas (Heaton, 2000) and giving suggestions for how to deal with those ideas (Collopy, 2003) may be especially important. Additional support for PCK is likely to be of help, as well, including support for knowledge about instructional representations such as analogies, models, or diagrams (Schneider & Krajcik, 2002; Wang & Paine, 2003).

Second, curriculum materials could support teachers' learning of subject matter (Ball & Cohen, 1996; see also Heaton, 2000; Schneider & Krajcik, 2002; Wang & Paine, 2003). Schneider and Krajcik found that teachers read, understood, and adopted ideas from the subject matter supports in the curriculum materials that they were using, in addition to learning subject matter from the descriptions of students' alternative ideas. Usually, support for subject matter knowledge refers to learning the facts and concepts within a subject; but it could and should also include the disciplinary practices within the subject area.

Third, curriculum materials could help teachers consider ways to relate units during the year (Ball & Cohen, 1996). Wang and Paine (2003) found that a teacher benefited from the objectives provided in the text of a mandated curriculum; the objectives fostered reflection for the teacher in considering how she presented the lesson in the context of the larger curricular picture.

In looking at these first three roles for educative curriculum materials, we see that educative elements can help teachers add important new ideas to their repertoires (e.g., about subject matter or students' likely ideas). The educative elements help teachers develop their knowledge base.

A fourth role that educative curriculum materials could play is to make visible the developers' pedagogical judgments (Ball & Cohen, 1996; see also Heaton, 2000; Petish, 2004). Curriculum materials should "speak to" teachers about the ideas underlying the tasks rather than merely guiding their actions (Remillard, 2000, p. 347); in doing so, the materials should educate teachers while promoting their autonomy (Shkedi, 1998) and help teachers to make decisions about how to adapt curriculum materials. Making rationales for decisions visible is one way that curriculum materials could move beyond simply adding new ideas to teachers' repertoires and, instead, help them to integrate their knowledge base and make connections between theory and practice—taking advantage of how curriculum materials are situated in teachers' work. Doing so would help teachers apply their knowledge more flexibly.

A fifth role that we recommend for educative curriculum materials is to promote a teacher's *pedagogical design capacity,* or his ability to use personal resources and the supports embedded in curriculum materials (i.e., the curricular resources) to adapt curriculum to achieve productive instructional ends (Brown & Edelson, 2003). Curriculum writers develop a text that teachers use; teachers decide how to enact lessons in reality (Ben-Peretz, 1990; Clandinin & Connelly, 1991). Ideally, teachers either make changes that remain true to the essence of the original curriculum materials or decide deliberately to move away from that essence (Bridgham, 1971), rather than inadvertently making changes that act as a "lethal mutation" (Brown & Campione, 1996, p. 291). Being able to make good decisions about changes may be especially important given the poor overall quality of typical curriculum resources (Hubisz, 2003; Kesidou & Roseman, 2002) and the concomitant need for teachers to adapt curriculum materials for local conditions (Barab & Luehmann, 2003). Each of the first four suggestions for educative curriculum materials outlined above could contribute to increasing the curricular and personal resources available to teachers and thus helping them find productive ways of adapting curriculum materials. Promoting a teacher's pedagogical design capacity can help him participate in the discourse and practice of teaching; rather than merely implementing a given set of curriculum materials, the teacher becomes an agent in its design and enactment.

Design Heuristics for Educative Curriculum Materials

We built on these high-level guidelines to develop an initial set of nine design heuristics intended to inform specific design decisions for educative curriculum materials (see Appendix for the heuristics and examples of their application). These heuristics focus on curriculum materials for science. A design framework such as this one needs to be grounded in real challenges that learners face, and many of the challenges that teachers face as learners differ according to subject area. We organized our heuristics around important parts of a teacher's knowledge base: subject matter knowledge, PCK for topics, and PCK for disciplinary practices. Although teachers have PCK for disciplinary practices across multiple components of PCK (assessment, students' ideas, etc.), we focus here on instructional strategies. Thus this set of nine heuristics is not exhaustive in coverage or domain. We have limited our analysis to restrict the scope of the work, and we encourage others to expand on our effort.

Developing the Design Heuristics and the Issue of Generality

In determining our design heuristics, we built on the approach of Quintana and colleagues (2004), who combined theory-driven analyses with inductive ones to develop a design framework for the design of ways to scaffold students' inquiry in learning technologies. For our theory-driven analysis, we characterize the challenges teachers face; for our inductive analysis, we identify ways that those challenges can be addressed through educative curriculum materials. To elaborate, we started by considering the challenges described in the literature, restricting our analysis to science teaching, and then grouped them. In identifying and grouping challenges, we noted that particular groups of teachers (e.g., beginning teachers, elementary teachers, teachers teaching out of their content area) face specific challenges that are less important for other groups. But for this analysis we combined similar challenges despite those differences, because a general set of design heuristics is useful as we think about the range of features that educative curriculum materials might need. (We return later to the issue of providing guidance tailored for specific types of teachers. Furthermore, we have elsewhere elaborated on the design heuristics, discussing challenges, strategies, and examples associated with each; see Davis & Krajcik, 2004.)

We then developed a design heuristic for each group of challenges and noted existing recommendations from the literature that could inform the ones we were developing, including ideas from the high-level guidelines reviewed above. For each design heuristic, we identified strategies that *could be applied* in the design of curriculum materials. Finally, we identified examples of how the strategies *have been incorporated* into our own groups' elementary and middle school curriculum development (in the Curriculum Access System for Elementary Science, or CASES project [see Davis, Smithey, & Petish, 2004]; and the Center for Highly Interactive Classrooms, Curricula, and Computing in Education, or hi-c^{3}e group [see Krajcik, Blumenfeld, Marx, & Soloway, 1994; Krajcik et al., 1998]).[2] Some of our materials have been developed in partnership with evaluators from the American Association for the Advancement of Science Project 2061. This helps to ensure the materials' baseline scientific and pedagogical quality.

Our design heuristics are grounded in the subject area of science because that is the area of our own expertise. We speculate that our *framework*—including subject matter knowledge, PCK for topics, and PCK for disciplinary practices—is general across most subject areas and that those with expertise in other domains can use the framework in developing design heuristics that apply to their domains. The *design heuristics themselves* may apply as templates across disciplines to varying degrees. For example, teachers of any subject area need subject matter knowledge and knowledge of students' likely intuitive and non-normative ideas.

Because inquiry is a prevalent idea in science education, we refer to PCK for disciplinary practices in science as *PCK for scientific inquiry*. The design heuristics that focus on PCK for scientific inquiry would require the most substantial changes to apply in another domain. We organized those heuristics around essential features of scientific inquiry. Disciplinary practices differ across domains, but there are some clear parallels. For example, in English language arts education, curriculum materials for engaging high school students in writing research papers might have educative elements that would help teachers engage students in asking important and researchable questions, collecting and analyzing sources, developing theses, building arguments, and communicating ideas.

Recall that in contrast to the guidelines reviewed above, our design heuristics are intended to help inform specific curriculum design decisions. The current list will clearly be especially useful for designers of science materials. But we also offer it as a context within which we can discuss larger issues of teacher learning promoted by educative curriculum materials—a discussion that is less dependent on the particular domain under discussion.

The Substance of a Design Heuristic

What makes these design heuristics different from the high-level guidelines that we presented earlier? Each design heuristic includes three components: It indicates what the curriculum materials should provide for teachers, how curriculum materials could help teachers understand the rationale behind the recommendations, and how teachers could use these ideas in their own teaching. In other words, each heuristic is designed to help curriculum developers see how to help teachers add new ideas to their repertoires of ideas (i.e., develop their knowledge base) and connect theory to their *own* practice (i.e., integrate their knowledge base and begin to use it flexibly in their teaching).

Design Heuristic 5, for example, focuses on engaging students with data. What challenges could curriculum materials that employ that heuristic help teachers to overcome? Even expert science teachers struggle to help students make careful observations, distinguish between observations and inferences, collect and compile data, and see trends (e.g., Crawford, 2000; Lehrer & Schauble, 2002). To address these challenges, Design Heuristic 5 recommends that

> Curriculum materials should provide teachers with approaches to help students collect, compile, and understand data and observations; help teachers understand why the use of evidence is so important in scientific inquiry; and help them adapt and use these approaches across multiple topic areas even when the data being collected seem fairly different (e.g., plant growth versus weather conditions).

Design Heuristic 5 suggests that educative curriculum materials should provide teachers with approaches for helping students collect and use data. One strategy might be to provide teachers with data tables to give to their students to help them keep track of their data, as well as guidance for how teachers could use them; such data tables might be provided in typical curriculum materials, too. The heuristic then states that curriculum materials should help teachers understand why the recommended approaches are appropriate. The materials might explain that students often have trouble organizing their data systematically; such an observation may seem trivial, but helping teachers make the connection back to a piece of common knowledge is a critical function of curriculum materials if they are to be generative and thus educative for teachers. Finally, Design Heuristic 5 suggests that curriculum materials should help teachers adapt and use these approaches across multiple topic areas—for example, by recommending that a similar data table structure be used consistently across units until students are ready to take over the process of designing data-recording strategies themselves.

Curriculum materials that incorporate all three components (i.e., instructional approaches, rationales for using the approaches, and recommendations for their effective use) may promote teacher learning and help teachers overcome challenges that they face, as we describe next.

How Educative Curriculum Materials Promote Teacher Learning: An Example

When learners add new ideas to their repertoires and make connections between them (Linn et al., 2004), they develop more integrated and robust knowledge and can apply that knowledge to new situations (Spiro, Feltovich, Jackson, & Coulson, 1991). Educative curriculum materials can promote these learning processes for teachers. Furthermore, teacher learning is situated in teachers' practice and distributed across individuals and cognitive tools (Putnam & Borko, 2000). Educative curriculum materials are inherently situated in practice and can serve as important cognitive tools for teachers. Finally, teacher learning should help teachers appropriate the social norms of teaching (Putnam & Borko, 2000). Educative curriculum materials can promote this enculturation into teacher discourse and practice, as well. We use an example to illustrate educative curriculum materials' role in promoting all of these processes and practices.

First, consider how educative curriculum materials serve as cognitive tools to help teachers add new ideas to their repertoires. The new ideas can be both specific and general. Specific ideas (e.g., instructional approaches to use) can be situated in teachers' own daily practice. More general ideas (e.g., rationales for using a particular instructional approach) should allow teachers to abstract from a particular situation to a more general rule.

Consider an example grounded in Design Heuristic 4, about supporting students in engaging in scientific questions. CASES, an online learning environment providing educative curriculum materials for preservice and beginning elementary and middle school teachers who teach science, incorporates narrative "images of inquiry," or stories that describe how fictional beginning teachers teach particular CASES lessons (Davis et al., 2004). These narratives are associated with specific lessons in the unit and are included in the lesson plans themselves. In the CASES astronomy unit for middle school, one lesson focuses on generating student questions about astronomy, and the narrative image of inquiry associated with the lesson describes how a beginning teacher named Jenny tries to incorporate students' questions into her unit while still meeting her district's objectives (see Figure 1).

This example shows how the narrative might help a teacher to add a specific instructional approach to her repertoire: The narrative describes what a teacher can do with the many questions that students generate that are not necessarily relevant to the standards the teacher is attempting to cover. It might also help the teacher understand the rationale for engaging students in asking and answering scientific questions (one essential feature of scientific inquiry; National Research Council, 2000). Jenny wants to use questions to help the students see astronomy's relevance to their lives and thus appreciate the importance of the topic. The teacher who reads this story may add at least two ideas to her repertoire—an instructional approach and a rationale for an instructional approach. Thus she has improved her knowledge base. To some extent, she can also become more enculturated into aspects of the discourse and norms of science inquiry and inquiry-oriented science teaching through exposure to and interaction with the expertise of another teacher. For example, she can gain an appreciation for the role of questioning in scientific inquiry and the ways that inquiry-oriented science teachers can incorporate questioning into their science teaching. (Participating in face-to-face or online discussions with other teachers who are engaged in inquiry-oriented science teaching would more directly contribute to the teacher's enculturation. Such discussions could build on ideas from the narrative.)

In addition to helping teachers add new ideas to their repertoires and become enculturated into salient practices, educative curriculum materials can also serve as cognitive tools to help teachers make connections between general principles and specific instructional moves—to integrate their knowledge base and begin to use their knowledge flexibly in the classroom. The example described above illustrates how the situated nature of curriculum materials

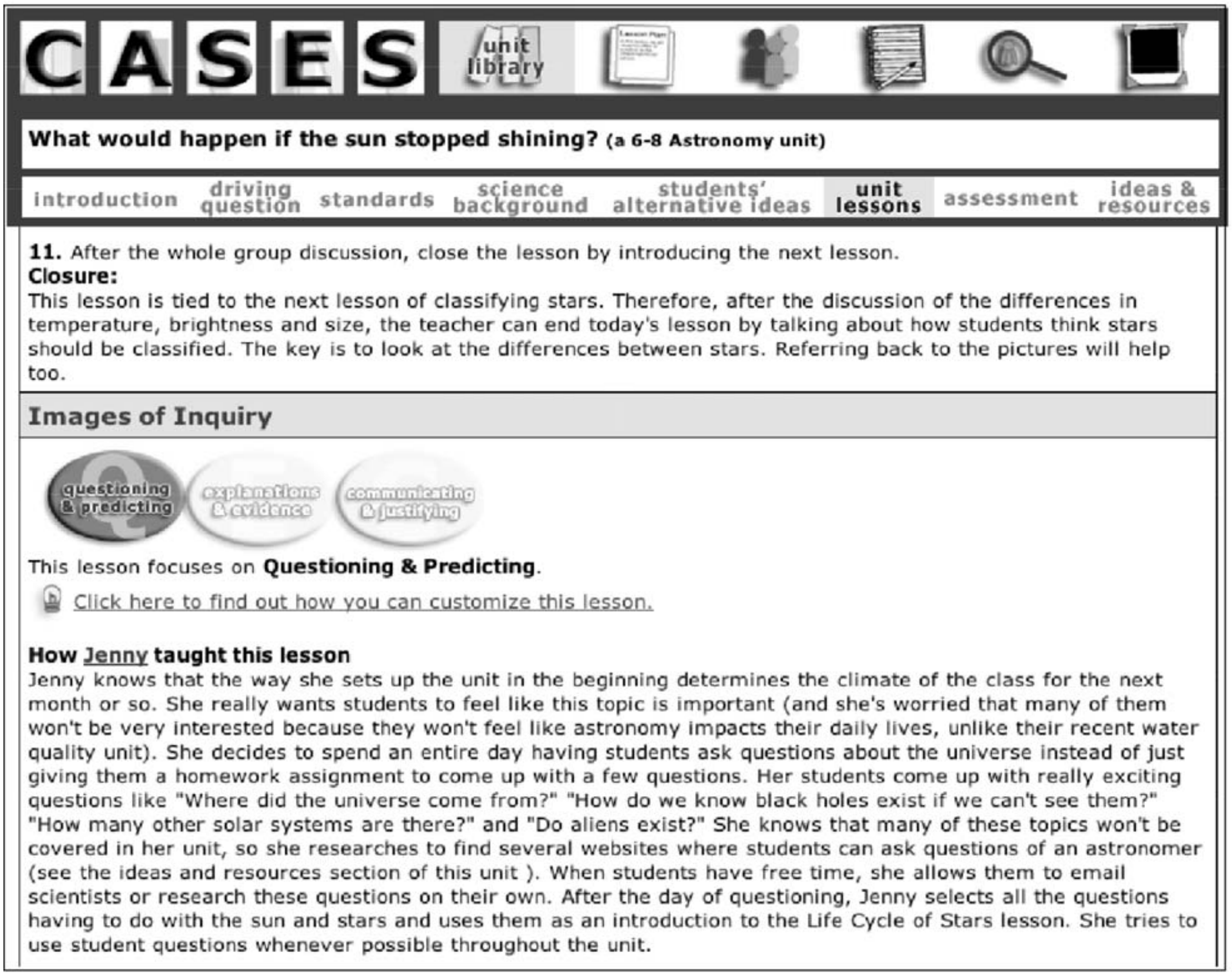

FIGURE 1. *At the bottom of a CASES lesson plan that focuses on the generation of student questions, a narrative image of inquiry illustrates how fictional teacher Jenny incorporates student questions into her lesson. Reprinted with permission of the CASES Research Group at the University of Michigan (copyright 2002).*

may promote the development of these connections; the principle (here, a rationale) is contextualized in both the lesson itself and a description of a teacher teaching the lesson.

By experiencing *many* of these situated educative elements across multiple contexts, a teacher generates links between the specific situations and a general principle. Why are these connections important? Teachers need to be able to apply their ideas to novel situations. A teacher might face a novel situation when she moves to a new school, where familiar lessons would need to be adapted to work in the new context. With sufficient robust connections between specific, situated instances and more general principles, the connections should allow the teacher to identify new situations as occasions where the general principle might apply and to recognize ways of applying it as she adapts novel curriculum materials. When this happens, the educative elements are generative for the teacher, in that they have prepared her for future learning (Bransford & Schwartz, 1999). They have also increased her pedagogical design capacity (Brown & Edelson, 2003), improving her ability to engage in a crucial teaching practice: adapting curriculum materials to increase fit with her own teaching context while not changing the materials in unproductive ways.

Limitations of Educative Curriculum Materials

Carefully designed educative curriculum materials have clear advantages. It is relatively straightforward to design materials that help teachers add new ideas to their repertoires. More challenging is to help them connect those ideas to other ideas. And harder still is helping them use their knowledge and engage in the discourse and practice of actual teaching.

We reiterate that the effectiveness of educative curriculum materials at promoting teacher learning will be limited by at least three factors in addition to those related to the design of the educative elements themselves. First, the "base" curriculum materials must be of high quality in terms of content and pedagogy. Second, their effectiveness is limited (or enhanced) by characteristics of the teachers themselves, such as their knowledge, beliefs, and dispositions toward reflection and improving their own practice (Collopy, 2003; Remillard, 1999; Schneider & Krajcik, 2002). Educative curriculum materials are not likely to support learning for every teacher. Third, used alone, educative curriculum materials serve as only one perturbation to the status quo. Data suggest that the presence of multiple sources for professional development is more effective than any one source (e.g., see Smith & Ingersoll, 2004); thus educative curriculum materials will almost certainly be more effective if used in conjunction with other forms of support.

Tensions in Designing Educative Curriculum Materials

Two other major and interrelated tensions arise in considering the design of educative curriculum materials. The first centers on determining an appropriate amount of guidance. The second centers on the design of materials appropriate for different sorts of teachers.

Tensions in Determining an Appropriate Amount of Guidance and Prescription

Teachers have many responsibilities. It is understandable, then, that there is a substantial practical problem in designing educative curriculum materials: Most teachers do not have time to read extensive curriculum materials—no matter how useful the materials might be.

How explicit should educative curriculum materials be in providing rationales? Being consistently explicit will frustrate some teachers who want only the instructions, especially given that some rationales will become redundant when included across multiple lessons. Yet other teachers thrive on knowing the reasoning behind suggestions that are being made. Identifying critical areas of understanding may help designers decide where to focus educative elements.

How prescriptive should the materials be? Teaching can be likened to performing surgery (Ball, personal communication, June 18, 2003; see also a quote from Albert Shanker in Stigler & Hiebert, 1999, p. 176). Just as we do not expect a surgeon to invent a new procedure each time she sees a patient, we should not expect a teacher to invent a new strategy for every new topic. For example, science educators widely recognize the important role that an approach called *bridging analogies* can play in helping physics students understand forces (Clement, 1993). Curriculum materials for high school physics classes would be remiss if they did not suggest how teachers could use bridging analogies.

But just as a surgeon needs to apply a standard procedure in a different way with each patient because every human body is different, so too does an expert teacher apply a standard approach differently in different situations. Part of being an expert is knowing how and when to make such adjustments. A teacher's pedagogical design capacity describes the teacher's ability to draw on the resources at hand to make productive changes to curriculum materials (Brown & Edelson, 2003). Applying the design heuristics provided here should promote this capacity. For example, if physics curricula included the rationale behind bridging analogies, teachers would be more likely to be able to apply the idea in additional contexts.

When curriculum materials provide too many choices, the selections that teachers make may not always promote the reform intended by the writers of the materials (Remillard, 1999). Yet being *too* prescriptive and ignoring or dismissing teachers' autonomy may also make the curriculum materials less effective. The science curriculum materials of the 1960s, for example, were not consistently successful, in part because they sometimes failed to take into account the teacher's role in making decisions (Welch, 1979). Likewise, the associated professional development did not support teachers in becoming facilitators rather than dispensers of information (Krajcik, Mamlok, & Hug, 2000). Recognizing these failings has led to greater consideration of the roles of teachers in interpreting curriculum materials (Clandinin & Connelly, 1991) and, more generally, a call for treating teaching as a learning profession (Darling-Hammond & Sykes, 1999). How might the effort to balance prescription and autonomy play out in educative curriculum materials? In CASES, as an example, teachers can view guidance designed to help them adapt lesson plans (Davis et al., 2004). The effectiveness of such a feature depends on how a teacher views his role vis-à-vis curriculum materials and as a lifelong learner more generally.

Tensions in Designing for Different Teachers

Designing for different types of teachers also presents a tension. Individual teachers interpret, use, and learn from curriculum in very different ways (Collopy, 2003; Lloyd, 1999; Remillard, 2000; Schneider & Krajcik, 2002). It stands to reason that groups of teachers, too, will vary in their use of curriculum materials.

For example, how should educative curriculum materials for beginning teachers differ from those for more experienced teachers? By virtue of being novices, beginning teachers lack the frameworks that more experienced teachers have for organizing new ideas about teaching. They also lack the knowledge that allows more experienced teachers to imagine how a lesson will play out in a classroom. Therefore, materials intended for beginning teachers would likely have a greater emphasis on helping teachers add new ideas to their repertoires; for instance, such materials might include more rationales. Because PCK is often described as being heavily dependent on teachers' experience (e.g., Magnusson et al., 1999), educative curriculum materials that are aimed at beginning teachers might include more extensive support for developing the many components of PCK. Because even experienced teachers may lack integrated subject matter knowledge and PCK to help them in teaching content to students, they, too, may benefit from guidance focused here. They may also benefit from support in engaging in more challenging teaching practices that move beyond ones they have mastered.

Alternative Structures for Delivering Curriculum Materials

Clearly, we need to think about the importance of form and format, as well as content, in educative curriculum materials, because all three dimensions play roles in addressing the two tensions described above. We may also need to think about alternative approaches to presenting curriculum. By delivering educative curriculum materials online, we have the opportunity to provide more information along the lines of the design heuristics presented here, using many different media (Davis et al., 2004; Fishman, 2003). For example, because complementing text with other media can promote more effective learning (Mayer, 2001) and because teachers learn from realistic descriptions of practice (Carter, 1993), online educative curriculum materials could incorporate audio and visual records of teachers' enactment of lessons.

Online, teachers could select the guidance that they think will help them. Beginning teachers might select guidance that would be ignored by more experienced teachers. Teachers might even be able to request different versions of lesson plans that incorporate more or less prescription, guidance, or choice.

But online solutions may not yet solve the problems that can arise in trying to promote teacher learning through educative curriculum materials. For example, some teachers print out lesson plans from the Web rather than reading them online, missing some educative aspects accessible by links (Petish, 2004). Of course, all of the guidance could be embedded in the text of the lesson plans, but then the length of the curriculum materials would become an even greater problem. The issues are so interrelated that a straightforward solution sometimes seems distant.

What Next?

How do we know whether educative curriculum materials really do promote teachers' learning? The design heuristics presented here can help curriculum developers create the educative curriculum materials that are necessary to test the theory that educative curriculum materials can promote the teacher learning necessary for educational reform. But testing the theory also requires solving ongoing problems in teacher learning research.

Answering the central question involves measuring teacher learning and characterizing teacher practice, as well as connecting teacher learning, teacher practice, and student learning. Teacher learning research lacks good ways of making these connections (Wilson & Berne, 1999), although progress is being made (Fishman, Marx, Best, & Tal, 2003; Garet, Porter, Desimone, Birman, & Yoon, 2001; Rowan, Correnti, & Miller, 2002). Answering the question also requires us to be able to map effects of specific features of the curriculum materials to specific aspects of the teachers' learning. Considering how the curriculum materials serve as cognitive tools that help teachers add new ideas and make connections between ideas provides a frame for such analyses. We could examine myriad data sources—lesson plans, classroom observations, interviews with teachers, student work—to look for evidence that particular ideas from educative curriculum materials have been taken up and enacted by teachers (Schneider & Krajcik, 2002).

Because our list of design heuristics is grounded in science and is non-exhaustive even within that subject area, research is needed to test the applicability of the heuristics in other subject areas and expand on this list. The design heuristics provided here must be tested empirically. Quasi-experimental studies could test different approaches, comparing narrative as opposed to expository forms of support or print as opposed to online delivery mechanisms. After testing and refinement of the heuristics, it might make sense to develop standards for the development of educative curriculum materials and nuanced criteria for evaluating existing curriculum materials from the standpoint of how educative they are for teachers. Finally, returning to the tensions described above, future research must determine which kinds of supports teachers want, need, and are willing to use. Rich case studies of how teachers use educative curriculum materials could prove effective here, especially if coupled with larger-scale research surveying teachers about their curriculum use and preferences.

In her presidential address at the 2004 annual meeting of the American Educational Research Association, Borko (2004) described three phases of research on professional development. Research on educative curriculum materials—a form of professional development, and one that we expect will become increasingly important in the coming decade—remains squarely in what Borko calls Phase 1, investigating a single intervention with a single group of teachers or in a single context. The goal of Phase 1 research is essentially to produce an existence proof that a professional development program (or, here, a set of educative curriculum materials) can positively affect teacher learning. Thanks to this type of foundational research, we in the field of educational research know a bit about how a few teachers use and learn from a few sets of educative curriculum materials. Yet we still know very little about how those materials are used by larger numbers of different types of teachers or how different educative curriculum materials, informed by different design rationales or complemented by different opportunities for additional professional development, compare to one another. We urge researchers to continue to explore the ways that educative curriculum materials can promote teacher learning and how their effects can be measured, on small and large scales. Doing so will help further our understanding of a form of professional development that holds promise for being both effective and efficient—if thoughtfully and carefully designed.

APPENDIX

Design Heuristics for Educative Science Curriculum Materials, with Examples and Elaborations Selected to Illustrate a Range of Supports

I. Design Heuristics for PCK for Science Topics

Design Heuristic 1—Supporting Teachers in Engaging Students with Topic-Specific Scientific Phenomena

> Curriculum materials should provide teachers with productive physical experiences that make phenomena accessible to students as well as rationales for why these experiences are scientifically and pedagogically appropriate. Curriculum materials should help teachers adapt and use these experiences with their students, for example by making recommendations about which experiments are important and feasible for students to conduct themselves and which might be more successful as demonstrations. Curriculum materials should warn of potential pitfalls with specific physical experiences. Curriculum materials should suggest and help teachers think about productive sequences for experiences.

Example:

The "What is the quality of our air?" unit developed by hi-c^{3}e suggests using a partially deflated and then fully inflated volleyball to demonstrate that air has mass and takes up space, and thus is matter. The curriculum materials explain why this demonstration works and is better, from a scientific standpoint, than a more typical demonstration using a balloon.

Design Heuristic 2—Supporting Teachers in Using Scientific Instructional Representations

> Curriculum materials should provide appropriate instructional representations of scientific phenomena (e.g., analogies, models, diagrams) and support teachers in adapting and using those representations, for example by noting changes that would lead to inaccuracies with regard to the science content. Curriculum materials should be explicit about why

a particular instructional representation is scientifically and pedagogically appropriate and what non-scientific ideas it might promote if used improperly. The curriculum materials should help teachers determine the most salient features of an instructional representation.

Example:

The hi-c[3]e unit "How can I make new stuff from old stuff?" suggests that students build gumdrop models of reacting materials and then physically take them apart to form the products that are formed. The materials explain the importance of using this representation and linking it to the macroscopic phenomena.

Design Heuristic 3—Supporting Teachers in Anticipating, Understanding, and Dealing with Students' Ideas About Science

Curriculum materials should help teachers recognize the importance of students' ideas and help teachers identify likely student ideas within a topic. Curriculum materials should help teachers gain insight into how they might be able to deal with the ideas in their teaching, for example by giving suggestions of thought experiments likely to promote the development of more scientific ideas.

Example:

Each CASES unit provides teachers with a set of ideas that the research indicates students at that age might hold (e.g., that air and wind are interchangeable concepts). Associated with each idea is a brief discussion of the normative scientific idea and suggestions for dealing with the idea in the classroom, such as a pointer to a lesson plan, suggestions about language to use or avoid, or thought experiments that students might perform.

II. Design Heuristics for PCK for Scientific Inquiry

Design Heuristic 4—Supporting Teachers in Engaging Students in Questions

Curriculum materials should provide driving questions for teachers to use to frame a unit and should help teachers identify questions that they can use with their students, including focus questions for guiding a class discussion. Curriculum materials should help teachers understand why these are scientifically and pedagogically productive questions. Curriculum materials should help teachers engage their students in asking and answering their own scientific questions, by providing suggestions of productive questions and ideas about how to guide students toward those or other productive questions.

Example:

Some CASES lessons include narrative "images of inquiry" connected to the lesson and describing how a fictional teacher dealt with questioning. (An example is elaborated in the text.)

Design Heuristic 5—Supporting Teachers in Engaging Students With Collecting and Analyzing Data

Curriculum materials should provide teachers with approaches to help students collect, compile, and understand data and observations; help teachers understand why the use of evidence is so important in scientific inquiry; and help them adapt and use these approaches across multiple topic areas even when the data being collected seem fairly different (e.g., plant growth as opposed to weather conditions).

Example:

A lower elementary CASES unit on plants includes narrative images of inquiry, such as one describing how a fictional first-grade teacher helped her students overcome challenges in making detailed observations of a seed (e.g., by encouraging them to use multiple senses and directing their attention to a poster of the five senses). The image of inquiry provides techniques that elementary teachers can apply in other topic areas for which physical observation is important.

Design Heuristic 6—Supporting Teachers in Engaging Students in Designing Investigations

Curriculum materials should help teachers recognize the importance of sometimes having students design their own investigations. Curriculum materials should provide guidance for how teachers can support students in doing so, by providing ideas for appropriate designs and suggestions for improving students' inappropriate designs.

Example:

In the hi-c[3]e unit "Can good friends make me sick?" students explore the growth of bacteria (Hug & Krajcik, 2002). First, the teacher models the process of conducting an investigation, and the students draw conclusions. Next, students ask their own questions and design their own experiment, using techniques similar to those the teacher demonstrated. The curriculum materials stress how important it is for the teacher to model these various components of inquiry because middle school students have difficulties in doing inquiry investigations. The materials are complemented by online video materials on the KNOW website featuring teachers talking about their classroom experiences with this set of lessons.

Design Heuristic 7—Supporting Teachers in Engaging Students in Making Explanations Based on Evidence

Curriculum materials should provide clear recommendations for how teachers can support students in making sense of data and generating explanations based on evidence that the students have collected and justified by scientific principles that they have learned. The supports should include rationales for why engaging students in explanation is important in scientific inquiry and why these particular approaches for doing so are scientifically and pedagogically appropriate.

Example:

The hi-c[3]e unit "How I can I make new stuff from old stuff?" emphasizes scientific explanations. The unit defines a scientific explanation and walks through the claim, evidence, and reasoning in an example of a student-generated explanation.

Design Heuristic 8—Supporting Teachers in Promoting Scientific Communication

Curriculum materials should provide suggestions for how teachers can promote productive communication among students and teachers in conversations and student artifacts. The curriculum materials should provide rationales for why particular approaches for promoting communication (e.g., class discussions, student presentations, lab reports) are scientifically and pedagogically appropriate.

Example:

CASES, which provides educative curriculum materials online, incorporates guidance-on-demand (Bell & Davis, 2000) to provide support for engaging in inquiry practices. Clicking on a tip link takes the teacher to a small pop-up window providing an answer to a question about *why* one would want to use a practice like communicating and justifying ideas (to provide a rationale for the practice) and *how* one could accomplish the practice—guidance that beginning teachers, in particular, are likely to need.

III. Design Heuristic for Subject Matter Knowledge

Design Heuristic 9—Supporting Teachers in the Development of Subject Matter Knowledge

Curriculum materials should support teachers in developing factual and conceptual knowledge of science content, including concepts likely to be misunderstood by students. Support should be presented at a level beyond the level of understanding required by the students, to better prepare teachers to explain science concepts and understand their students' ways of understanding the material. Curriculum materials should help teachers see how the scientific ideas relate to real-world phenomena and to the activities in the unit and why strong subject matter knowledge is important for teaching.

Example:

The science background sections of CASES units use lay terminology and real-world examples as much as possible, with scientific terminology carefully defined. The CASES weather unit answers questions such as "How do our observations help us predict tomorrow's weather?" and makes connections to puddles on the street in the discussion of the water cycle.

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[1] We use *students* to refer to K–12 pupils. We distinguish among *preservice teachers* in schools of education, *beginning teachers* in their early years of teaching, and *experienced teachers* who have taught for several years. We use *teachers* to refer to preservice teachers and practicing teachers with any level of experience.

[2] CASES is a technology-mediated learning environment provided on the Web (http://cases.soe.umich.edu), aimed at supporting preservice and beginning elementary and middle school teachers as they learn to teach inquiry-oriented science more effectively. CASES incorporates inquiry-oriented unit plans that are educative for teachers, as well as a personal online journal, an online teacher community discussion space, and other resources for science teaching. Researchers from hi-c^{3}e (http://www.hice.org) use the principles of project-based science as a design framework for the curriculum materials that they develop. The curriculum materials developed by hi-c^{3}e and widely used in schools are made educative for teachers through the inclusion of science background knowledge and suggestions for successful enactment. The printed curriculum materials are supplemented by extensive professional development, including regular workshops and an online resource called Knowledge Networks on the Web (KNOW; see http://know.soe.umich.edu/).

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