

USING EDUCATIVE CURRICULUM MATERIALS TO SUPPORT TEACHERS IN DEVELOPING PEDAGOGICAL CONTENT KNOWLEDGE FOR SCIENTIFIC MODELING

To successfully engage their students in scientific modeling, teachers require multiple domains of knowledge, including pedagogical content knowledge for scientific modeling. This special type of knowledge can be viewed through the knowledge integration perspective as the integration of multiple types of ideas. Educative curriculum materials, or curriculum materials designed with the intention of supporting teacher learning in addition to student learning, can promote the knowledge integration processes of identifying weaknesses with ideas, adding ideas to one's repertoire, and making links between ideas; at the same time these materials support conceptual change processes such as promoting dissatisfaction with some ideas and the intelligence, plausibility, and fruitfulness of others. Educative science curriculum materials designed with the intention of promoting the development of pedagogical content knowledge for scientific modeling are described, illustrating how specific forms of text are used to promote these teacher learning processes.

Elizabeth A. Davis, University of Michigan

Michele Nelson, University of Michigan

Carrie Beyer, University of Michigan

Introduction

Teachers have multiple types of knowledge, including subject matter knowledge, pedagogical knowledge, and pedagogical content knowledge, or PCK (Shulman, 1986). PCK in science includes a teacher's knowledge of science learners, curriculum, instructional strategies, and assessment (Abell, 2007; Magnusson, Krajcik, & Borke, 1999). While PCK is typically conceptualized as topic-specific, teachers also need discipline-specific knowledge about how a discipline works. For example, science teachers need PCK for scientific inquiry (Davis & Krajcik, 2005) and PCK for scientific modeling (Justi & van Driel, 2005, 2006; Schwarz, Meyer, & Sharma, 2007). PCK for scientific modeling provides the focus of this paper. Teachers may have limited or disconnected ideas about using scientific modeling in classrooms, and thus PCK for scientific modeling is a prime candidate to target for teacher learning, knowledge integration, and conceptual change.

PCK for scientific modeling incorporates knowledge of instructional strategies that can promote students' engagement in modeling practices and learning of epistemological/metamodeling knowledge, or higher-level knowledge such as the purposes models can serve. PCK for scientific modeling also incorporates teachers' knowledge of their students' ideas and challenges, again associated with scientific modeling. To have strong PCK for scientific modeling, of course,

teachers must themselves understand modeling practices and hold metamodeling knowledge, as well.

But what are models and modeling, and how are they used in schools? A scientific model is an abstraction and simplification of a system that make its central features explicit and visible, allowing someone—a scientist, a teacher, or a learner—to illustrate, generate explanations, or make predictions of natural phenomena (Harrison & Treagust, 2000). Such models are the result of scientific modeling practices, or constructing, using, evaluating, and revising models. Scientific modeling is rarely incorporated into educational experiences of elementary or middle school students. Many teachers have limited knowledge of models and modeling and also of students' ideas about models and modeling (Justi & Gilbert, 2002; van Driel & Verloop, 2002). Teachers often see models as useful for teaching about science content, but not about the nature of science (Henze, van Driel, & Verloop, 2007; Justi & Gilbert, 2002; van Driel & Verloop, 2002). For these and other reasons, many science teachers need support to effectively engage their students in scientific modeling (e.g., Justi & Gilbert, 2002; Justi & van Driel, 2005, 2006; Windschitl & Thompson, 2006)—perhaps especially elementary and middle school teachers, who may have less sophisticated knowledge of science in general compared to their high school counterparts.

In the MoDeLS (Modeling Designs for Learning Science) project, we work with preservice and inservice teachers to support them in learning to incorporate scientific modeling into their classrooms. Here, we focus on our design of educative curriculum materials to promote teacher learning of pedagogical content knowledge for scientific modeling. *Educative curriculum materials* are intended to promote teacher learning as well as student learning (Ball & Cohen, 1996; Davis & Krajcik, 2005). These materials are one approach for supporting teachers in developing PCK (Schneider, 2006), including PCK for scientific modeling. Educative curriculum materials are hypothesized to be an especially fruitful form of support for teacher learning because they are contextualized in teachers' daily practice. Our educative curriculum materials are intended to help teachers learn to engage students in modeling, within the context of our upper elementary and middle school modeling-enhanced curriculum materials.

Theoretical Framework

The knowledge integration perspective has been used mainly in analyzing students' learning of science and other subjects (e.g., Clark & Linn, 2003; Davis, 2003; Davis, Linn, & Clancy, 1995; Linn, Davis, & Bell, 2004; Linn & Hsi, 2000), allowing rich descriptions of learning and identification of mechanisms or processes that support learning. In this sociocognitive perspective, learners hold a repertoire of ideas, some of which are intuitive and others that are instructed. Learners *identify weaknesses* in their knowledge and *add new ideas* to their repertoire, *making links* between some of them (Linn & Hsi, 2000; see also Smith, diSessa, & Roschelle, 1994). For science students, knowledge integration involves applying these knowledge integration processes to ideas such as scientific principles, real-world experiences, and classroom-based experiences to develop robust and usable understandings (Davis, 2003; Linn & Eylon, 1996). This perspective on conceptual change emphasizes how learners may come to be dissatisfied with existing ideas and come to view a new idea as intelligible, plausible, and fruitful (Strike & Posner, 1992), by focusing on the shifts that take place within a learner's repertoire of ideas.

Knowledge integration, because of its emphasis on connecting ideas, is a promising lens through which to view the development of teachers' PCK (Davis, 2004). Ma (1999), building on earlier work done by Ball (1988), claims that teachers need well-integrated knowledge. Ma identifies links that allow teachers to apply their knowledge flexibly. Ball and Bass (2000) also describe the need for the flexibility of teachers' knowledge and the need to apply knowledge fluidly as teachers make decisions in the classroom. Lederman, Gess-Newsome, and Latz (1994) find that as teachers progress through a teacher education program, their knowledge becomes more interconnected, though others find that ideas from university courses and programs may remain unconnected to their foundational ideas developed through their experiences in schools or with phenomena (Lortie, 1975; Putnam & Borko, 2000; Wilson & Berne, 1999).

Pedagogical content knowledge as initially defined by Shulman (1986) and later elaborated by many others (e.g., Appleton, 2003; Grossman, 1990; Magnusson et al., 1999; McDiarmid, Ball, & Anderson, 1989; Treagust & Harrison, 2000) includes components such as knowledge of instructional strategies, instructional representations, classroom explanations, students' ideas, and curriculum. This special knowledge held by teachers requires what some refer to as a transformation of subject matter knowledge and pedagogical knowledge (e.g., Magnusson et al., 1999) but what could also be viewed as the well-integrated knowledge base of an effective teacher. PCK for scientific modeling, for instance, requires meaningful integration of ideas about subject matter, models, modeling, learners, learning, and instruction. To develop this special knowledge, a teacher may need to (for example) add new metamodeling knowledge about models and modeling, add a new specific idea about a specific instructional approach, connect these to an existing idea about learners, and so forth.

Educative curriculum materials provide a form of support for teacher learning, knowledge integration, and conceptual change. Educative curriculum materials serve as cognitive tools (Grossman & Thompson, 2004; Putnam & Borko, 2000) to support teachers in engaging in their practice but also in learning in and from their practice. While PCK improves, not surprisingly, with teaching experience, even beginning teachers can develop "PCK readiness" (Smithey, 2008) and educative curriculum materials should be able to at least support the development of this readiness and poise teachers for ongoing knowledge development and integration over time.

Educative Curriculum Materials as Support for Developing PCK-SM

Specific features of educative curriculum materials can support specific aspects of teacher learning, such as identifying weaknesses or creating dissatisfaction with a current idea, adding new ideas about specific instructional strategies to teachers' repertoires of ideas, adding new general principles of practice to their repertoires, adding other new general ideas (such as dimensions of metamodeling knowledge), determining the plausibility and fruitfulness of new ideas, and making connections between ideas. Educative features facilitate these processes and work in concert to promote the development of PCK.

We use examples from our MoDeLS curriculum materials to illustrate how educative curriculum materials can promote the development of PCK for scientific modeling (PCK-SM). Specifically, we draw on the "front matter" (Nelson, Beyer, & Davis, 2008) we developed to be inserted into our various modeling-enhanced curriculum materials (or as a stand-alone reading for preservice and inservice teachers interested in modeling). The front matter incorporates expository text

(about models and modeling—i.e., metamodeling knowledge—as well as instructional strategies and principles of practice, which feed into PCK-SM). It also incorporates narratives about a fictional fourth-grade teacher named Ms. Garcia who is engaging in modeling seed dispersal with her students. Such narratives have been found in our previous work to be effective cognitive tools for preservice teachers (e.g., Beyer & Davis, 2008; Dietz & Davis, in press), making new ideas more intelligible and plausible through illustrating them with classroom examples. For our examples, we also draw on one sixth grade unit focused on light (Fortus et al., 2008) developed originally for the Investigating and Questioning our World through Science and Technology project and enhanced in the context of the MoDeLS project to better support engagement in modeling. The Light unit incorporates educative elements in the form of expository text about metamodeling knowledge, instructional strategies, principles of practice, and learners' ideas associated with modeling, all grounded in modeling-relevant lessons.

How can educative curriculum materials support specific knowledge integration and conceptual change processes? Educative curriculum materials can help teachers *identify a weakness* with their current ideas, or, in other words, can *create some dissatisfaction* with ideas. As an example, consider the following text from the MoDeLS front matter:

This all may be different from how you learned science when you were a K-12 student. Nowadays, science educators tend to avoid the "scientific method" because it gives students a false sense of a linear progression with a final "right answer." Plus, scientists themselves tend to favor approaches that are more iterative and encompass a wider range of scientific practices, including scientific modeling. (from MoDeLS front matter, January 2008)

The text attempts to create dissatisfaction with the status quo (in this case, the use of the scientific method in science education) through providing a rationale in the form of some additional information about how scientists work—ideas with which most teachers, especially at the elementary and middle school level, may not be familiar.

Educative curriculum materials can also help teachers *add an idea* about a specific instructional approach (and thus make a new idea both *intelligible* and *plausible*). For example, consider a narrative about how Ms. Garcia engages her students in evaluating their diagrammatic models of seed dispersal:

... When everyone was back in their seats, Ms. Garcia said "Ok, everyone, let's take out our models of forest plant seed dispersal and *think about how our models compare to what we observed* on our field trip today." ... Ms. Garcia then *gave each student a rubric with a list of criteria* that they had developed during a previous unit and asked students to work in groups to *evaluate how well their models met the criteria*, and she *reminded them* that they would be evaluating the idea models and the picture models. ... (from MoDeLS front matter, January 2008; italics added)

The italicized text highlights different specific instructional approaches this short excerpt makes visible to readers. Ms. Garcia encourages her students to think about the relationship between their models and their observations of actual seed dispersal. She provides students with a rubric listing criteria for evaluating models (elsewhere, the front matter says that such criteria may include ideas like accuracy, consistency, and clarity, among others), and she supports them in evaluating how well their models meet the criteria. Furthermore, she reminds them of the

importance of evaluating not just the diagrams themselves (referred to here as the "picture models"), but also the "idea models" (or the science behind the diagrams). These are all important instructional strategies for successfully engaging students in model evaluation (and thus are an aspect of PCK-SM). In addition, the last instructional strategy also connects to another aspect of PCK-SM, namely knowledge of learners' likely ideas. Ms. Garcia knows that students are likely to be overly concerned with the aesthetics of their models, at the expense of considering the scientific accuracy and consistency with evidence, so she explicitly reminds them to address both. While the italicized instructional strategies represent specific instructional ideas that can be added to a teacher's repertoire of ideas, they also work to make the new overarching idea (of model evaluation, in this case) more intelligible and plausible for teachers, by illustrating, using a narrative, what this might look like in the classroom.

Similarly, in the Light unit, we use the educative elements to suggest a teaching strategy:

You might want to start a chart titled "Features of Models and Modeling" on which you can record important ideas about modeling over the course of the unit. When you introduce a new idea about modeling, you can write it on the chart, and when you revisit the idea, you could remind students about it using the chart. (from Light unit, January 2008)

Here, a strategy that is returned to throughout the unit is introduced. The strategy is intended to help teachers help students develop their metamodeling knowledge. The educative support goes on to describe what the chart might eventually look like by the end of the unit. This serves to provide a specific instructional strategy the teacher can use regularly—adding a new specific instructional idea to the teacher's repertoire. Later in the unit, reminders are provided. For example:

Explain to [students] that an important aspect of a **good** scientific model is that it can account for the existing evidence; use the term "consistency" to help them begin to recognize this as an important aspect of models. You might add this idea of consistency to your chart of "Features of Models and Modeling." (from Light unit, January 2008; emphasis in the original)

This, too, works to add a specific idea to the repertoire, and also serves to highlight for the teacher when a relevant aspect of metamodeling knowledge is being invoked.

But in designing educative curriculum materials, it is important to support teachers not just in adding new specific instructional ideas to their repertoire, but also to support them in *adding new general ideas* that they can apply in multiple situations. This serves to make the ideas in the repertoire more generative and thus more *fruitful*, by providing a more general concept to which other specific instances of the concept can be linked. One example is found in expository text intended to support adding ideas about the multiple purposes of models (an important dimension of metamodeling knowledge) to a teacher's repertoire. Here, the new idea being added is a dimension of metamodeling knowledge. Consider the following lengthy excerpt from the MoDeLS front matter:

After constructing (or revising) a scientific model, students and teachers may **use** their scientific model for a variety of purposes, including **generating or communicating ideas**. By generating ideas, we mean students can use their models to develop knowledge that's new (at least to them); this can also be called using a model for sense-

making, and can be done by an individual or group. By communicating ideas, we mean students can use models to share ideas with others. This distinction gets at for whom the model is being used—for oneself or one's group, or for others outside of one's group. Both of these ways of using models are important in science teaching and learning. At the same time models can be used to **illustrate**, **explain**, or **predict** systems or phenomena. This distinction reveals the kind of thinking the model is being used to accomplish.

First, scientific models may be used to **illustrate** systems or phenomena that are too difficult to observe directly (for example, phenomena that happen on too large or too small a scale or that cannot be manipulated). For example, the solar system model illustrates, roughly, the relative size of the planets and their order from their sun—a system that is too large to examine in real life.

A more sophisticated use of scientific models is to help **explain** phenomena. In one sense, scientific models can help a person clarify her own understanding of phenomena—as a sort of a “self-explanation” tool that contributes to the generation of new knowledge. Scientific models can also help students develop ideas about relationships between model components. For example, you might ask students to create a diagram of a food web to help them better visualize and keep track of the interactions between predators and prey, producers and consumers, etc. In turn, this food web might inspire you to add aphids to your garden at home in an attempt to keep plant-eating pests under control. ...

Finally, scientific models may also be used to **predict** outcomes. In this case, the student will use her model to theorize what the results might be when new experimental conditions or variables (or a new phenomenon or event) are encountered. For example, a student who has developed a model showing how insulation keeps soup warm in a thermos (by slowing the movement of heat) might use her model to predict how the same thermos might keep her drink cold. Again, this use of models can work toward the generation of new knowledge or the communication of existing knowledge. (from MoDeLS front matter, January 2008; emphasis in the original)

The purposes of models—for sensemaking and for communication—and, in a related vein, the types of work they can do—illustrating, explaining, and predicting—are crucial for teachers to understand. They are crucial because we know that teachers often do not use models for this range of work, focusing instead primarily on their use as pedagogical tools (Justi & Gilbert, 2002; van Driel & Verloop, 2002) that serve to communicate and illustrate ideas but that do not support students in making sense of complex scientific ideas or understanding their explanatory or predictive power. By adding these general ideas about the purpose of models to a teacher's repertoire, we support them in being better positioned to use scientific models effectively in the classroom; they may be better able to recognize, for example, when instructional strategies being suggested relate to the purpose of models. While this type of support may reasonably be considered support for the development of metamodeling knowledge itself, the instructional examples incorporated into the front matter text and juxtaposed with each explication of an aspect of metamodeling knowledge illustrate the integrated nature of the specialized knowledge we hope teachers will develop.

Of course, simply adding new ideas to one's repertoire unreflectively is unlikely to lead very efficiently to the development of robust PCK-SM. Teachers must also *connect ideas* to develop the integrated knowledge base they need. One important kind of connection that educative curriculum materials can (and should) support is the connection between an instructional idea, on

the one hand, and a rationale for the instructional approach (which may be a general principle of practice), on the other (Davis & Krajcik, 2005). Consider one example drawn from a narrative about Ms. Garcia supporting her students in constructing their initial models of seed dispersal:

Ms. Garcia asked her students to take out a piece of paper and pencil and begin drawing their ideas about forest seed dispersal. ... Ms. Garcia felt that having their ideas on paper (as expressed models) would make it more productive for students to compare their ideas, see where they agreed and disagreed, and come up with questions they needed to figure out in order to reach consensus. (from MoDeLS front matter, January 2008)

In the first sentence of this excerpt, we provide an idea about an instructional approach teachers can use—namely having students draw their ideas about the scientific phenomenon under consideration. The narrative continues, and then, in the last sentence of this excerpt, we provide the rationale for the instructional approach. Providing the rationale supports the possibility of not just adding to the repertoire the instructional idea ("have students draw their initial models") but also connecting it to a reason in the form of a principle of practice (the importance of promoting more productive discourse for later sensemaking with the models). By experiencing many such connected instructional-approaches-and-rationale sets, the teacher may be better positioned to use the instructional approach effectively in a future lesson.

Another example illustrates that expository text can also support such connections between ideas. In the following example, focused on using criteria for model evaluation, we attempt to support the connections among specific instructional ideas, rationales for those specific ideas in the form of more general principles of practice, and metamodeling knowledge:

Finally, you can help students develop and apply a set of criteria (or use a provided set of criteria) for evaluating their models. The criteria might include questions about the scientific accuracy, plausibility, and usefulness of their idea models and questions about the clarity, saliency, and group norms dealing with their expressed models. Talking about the criteria you're using will help students recognize the importance of evaluating not just how nice-looking their models are, but also how sound the underlying science is. Having students get into the habit of evaluating their models also helps them recognize an important feature of models: that any model has strengths and limitations. (from MoDeLS front matter, January 2008)

The first two sentences in this excerpt provide a recommendation for (a) having students use criteria to evaluate their models and (b) which criteria might be most fruitful to use. These are specific instructional ideas a teacher can use. The third sentence reinforces the rationale mentioned above—that it is important to consider not just the aesthetics of a model but also the underlying science. The final sentence of this excerpt then connects these two ideas in turn to an over-arching aspect of metamodeling knowledge discussed elsewhere in the front matter text—that all models have strengths and weaknesses. It also provides an additional rationale for engaging students in model evaluation: to help them develop their own metamodeling knowledge.

A final example, drawn from the Light unit, similarly illustrates the ways in which educative curriculum materials can promote links among multiple ideas:

As mentioned earlier, many different types of expressed models (such as physical objects, diagrams, and graphs) can be used to represent the same phenomenon.

Different models have different advantages and disadvantages, depending on the aspects of interest of the phenomenon being considered. In addition, models may sometimes mislead by suggesting characteristics that are not shared with what is being modeled and/or by not representing certain key aspects of the phenomenon.

Since [students] may think that physical objects and/or diagrams are the only type of expressed models, remind students that there are many other types of models – such as equations, simulations, graphs, etc. Mention examples that the [students] have had experience with in the past.

[Furthermore, since students] may not realize that models can have limitations, or may think a model's only limitation is how exact a replica it is, refer to the idea that models have various limitations as well as strengths. Talk about the importance of evaluating and revising models so they can better overcome those limitations and meet their intended purposes. ... (from Light unit, January 2008)

Here, two aspects of metamodeling knowledge are targeted, namely that different types of models can represent the same phenomenon and that different models have different advantages and disadvantages. For each dimension, students' likely ideas are stated, and are used as a rationale for an instructional recommendation. Three types of knowledge are connected, for each of two dimensions of metamodeling knowledge: the metamodeling knowledge itself, likely learners' ideas about the dimension of metamodeling knowledge, and what a teacher could do to try to address the learners' ideas.

Conclusion

Taking a knowledge integration perspective on teacher learning and conceptual change emphasizes considering the ideas in a teacher's repertoire and the network of connections among those ideas. This perspective is especially useful in theorizing about the development of PCK (Davis, 2004), which is often described using words like transformation, amalgam, intersection, or blend. It allows us to explore ways of promoting dissatisfaction with some ideas and the intelligence, plausibility, and fruitfulness of others.

The knowledge integration perspective raises questions about the notion that a learner's poor or less useful ideas are straightforwardly replaced with better ones. Instead, ideas are assumed to change in their cueing priority (Smith et al., 1994). More explanatory ideas become cued in more contexts and thus are used increasingly often, as learners gain knowledge and experiences and make new links. Other ideas with more limited explanatory success gradually become cued less often. Applied to designing opportunities for teacher learning, this perspective suggests that teachers likely need multiple experiences with educative elements in educative curriculum materials. Some of our prior work with preservice teachers using educative supports indicates that a single exposure is insufficient for effecting lasting change (Beyer & Davis, 2008). By providing similar types of support across different lesson plans, teachers may be more likely to increase the meaningful connections among ideas and to change the cueing priority of their ideas.

In sum, conceptualizing the development of an especially challenging form of PCK—PCK for scientific modeling—through the lens of knowledge integration allows us to make informed design decisions about our educative curriculum materials. We attempt to use these materials as

one form of support for teacher learning. We specifically emphasize the importance of considering multiple domains of knowledge that may need support—including science subject matter knowledge, metamodeling knowledge, knowledge of learners, and knowledge of instructional approaches. At the same time, this lens informs our focus on helping teachers identify weaknesses in their ideas, add new specific ideas (such as specific instructional approaches they can use to achieve certain ends) and more general ideas (such as rationales for those approaches in the form of principles of practice, or such as metamodeling knowledge itself), and making connections across the various ideas in the repertoire. Materials designed with these ideas in mind may improve teachers' knowledge integration and conceptual change in a challenging area, and support the beginning of the development of PCK for scientific modeling.

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