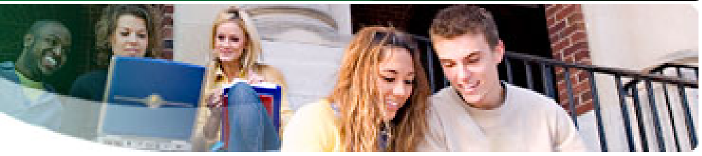

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Pedagogical Content Knowledge: Teachers' Integration of Subject Matter, Pedagogy, Students, and Learning Environments

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"Those who can, do. Those who understand, teach."
(Shulman, 1986, p. 14)

Introduction

Recently, there has been a renewed recognition of the importance of teachers' science subject matter knowledge, both as a function of research evidence (e.g., Ball & McDiarmid, 1990; Carlsen, 1987; Hashweh, 1987), and as a function of literature from reform initiatives such as the Holmes Group (1986) and the Renaissance Group (1989). Not surprisingly, it has become clear that *both* teachers' pedagogical knowledge and teachers' subject matter knowledge are crucial to good science teaching and student understanding (Buchmann, 1982, 1983; Tobin & Garnett, 1988).

The recent development of the National Science Education Standards (NRC, 1996) and the Benchmarks for Science Literacy (AAAS, 1993) as well as a multitude of state, district, and school level content area standards, have further renewed emphasis on the importance of subject matter. Moreover, these documents contain not only key subject matter concepts for student learning, but they also inform *pedagogical issues* related to science subject matter content.

The Nature of Pedagogical Content Knowledge

In addition to teachers' subject matter (content) knowledge and their general knowledge of instructional methods (pedagogical knowledge), *pedagogical content* knowledge was originally suggested as a third major component of teaching expertise, by Lee Shulman (1986; 1987) and his colleagues and students (e.g. Carlsen, 1987; Grossman, Wilson, & Shulman, 1989; Gudmundsdottir, 1987a, 1987b; Gudmundsdottir & Shulman, 1987; Marks, 1990). This idea represents a new, broader perspective in our understanding of teaching and learning, and a special issue of the *Journal of Teacher Education* (Ashton, 1990) was devoted to this topic.

Pedagogical content knowledge is a type of knowledge that is unique to teachers, and is based on the manner in which teachers relate their pedagogical knowledge (what they know about teaching) to their subject matter knowledge (what they know about what they teach). It is the integration or the synthesis of teachers' pedagogical knowledge and their subject matter knowledge that comprises pedagogical content knowledge. According to Shulman (1986) pedagogical content knowledge

> . . . embodies the aspects of content most germane to its teachability. Within the category of pedagogical content knowledge I include, for the most regularly taught topics in one's subject area, the most useful forms of representation of those ideas, the most powerful analogies, illustrations, examples, explanations, and demonstrations - in a word, the ways of representing and formulating the subject that make it comprehensible to others . . . [It] also includes an understanding of what makes the learning of specific concepts easy or difficult: the conceptions and preconceptions that students of different ages and backgrounds bring with them to the learning (p. 9).

Pedagogical content knowledge is a form of knowledge that makes science teachers teachers rather than scientists (Gudmundsdottir, 1987a, b). Teachers differ from scientists, not necessarily in the quality or quantity of their subject matter knowledge, but in how that knowledge is organized and used. In other words, an experienced science teacher's knowledge of science is organized from a *teaching* perspective and is used as a basis for helping students to understand specific concepts. A scientist's knowledge, on the other hand, is organized from a *research* perspective and is used as a basis for developing new knowledge in the field. This idea has been documented in Biology by Hauslein, Good, & Cummins (1992), in a comparison of the organization of subject matter knowledge among groups of experienced science teachers, experienced research scientists, novice science teachers, subject area science majors, and preservice science teachers. Hauslein et al. found that science majors and preservice teachers both showed similar, loosely organized subject matter knowledge; and that the subject matter knowledge of the novice and experienced teachers and the research scientists was much deeper and more complex. However, compared to the researchers (who showed a flexible subject matter structure), the teachers showed a more fixed structure, hypothesized to result from curriculum constraints.

Cochran, DeRuiter, & King (1993) revised Shulman's original model to be more consistent with a constructivist perspective on teaching and learning. They described a model of pedagogical content knowledge that results from an integration of *four* major components, two of which are subject matter knowledge and pedagogical knowledge. The other two other components of teacher knowledge also differentiate teachers from subject matter experts. One component is teachers' knowledge of students' abilities and learning strategies, ages and developmental levels, attitudes, motivations, and prior knowledge of the concepts to be taught. Students' prior knowledge has been especially visible in the last decade due to literally hundreds of studies on student misconceptions in science and mathematics. The other component of teacher knowledge that contributes to pedagogical content knowledge is teachers' understanding of the social, political, cultural and physical environments in which students are asked to learn. The model in Figure 1 shows that these four components of teachers' knowledge all contribute to the integrated understanding that we call pedagogical content knowledge; and the arrows indicate that pedagogical content knowledge continues to grow with teaching experience. The integrated nature of pedagogical content knowledge is also described by Kennedy (1990).

Figure 1. Pedagogical Content Knowledge in the Experienced Teacher

Research Evidence

Hashweh (1985, 1987) conducted an extensive study of three physics teachers' and three biology teachers' knowledge of science and the impact of that knowledge on their teaching. All six teachers were asked about their subject matter knowledge in both biology and physics, and they were asked to evaluate a textbook chapter and to plan an instructional unit on the basis of that material. Given a concept like photosynthesis for example, the biology teachers knew those specific misconceptions that students were likely to bring to the classroom (such as the idea that plants get their food from the soil) or which chemistry concepts the students would need to review before learning photosynthesis. The biology teachers also understood which ideas were likely to be most difficult (e.g. how ATP-ADP transformations occur) and how best to deal with those difficult concepts using a variety of analogies, examples, demonstrations and models. The biology teachers could describe multiple instructional "tools" for these situations; but, although they were experienced teachers, they had only very general ideas about how to teach difficult physics concepts. The physics teachers, on the other hand, could list many methods and ideas for teaching difficult physics concepts, but had few specific ideas for teaching difficult biology concepts.

When the teachers in Hashweh's study were asked about their subject matter knowledge in the field that was not their specific field, they showed more misconceptions, more misunderstandings, and a less organized understanding of the information. Within their own fields, they were more sensitive to subtle themes presented in textbooks, and could and did modify the text material based on their teaching experiences. Moreover, they were more likely to discover and act on student misconceptions. The teachers used about the same number of examples and analogies when planning instruction in both fields, but those analogies and examples were more accurate and more relevant in the teachers' field of expertise.

Other studies have shown that new teachers have incomplete or superficial levels of pedagogical content knowledge (Carpenter, Fennema, Petersen, & Carey, 1988; Feiman-Nemser & Parker, 1990; Gudmundsdottir & Shulman, 1987; Shulman, 1987). A novice teacher tends to rely on unmodified subject matter knowledge (most often directly extracted from the curriculum) and may not have a coherent framework or perspective from which to present the information. The novice also tends to make broad pedagogical decisions without assessing students' prior knowledge, ability levels, or learning strategies (Carpenter, et al., 1988). In addition, preservice teachers have been shown to find it difficult to articulate the relationships between pedagogical ideas and subject matter concepts (Gess-Newsome & Lederman, 1993); and low levels of pedagogical content knowledge have been found to be related to frequent use of factual and simple recall questions (Carlsen, 1987). These studies also indicate that new teachers have major concerns about pedagogical content knowledge, and they struggle with how to transform and represent the concepts and ideas in ways that make sense to the specific students they are teaching (Wilson, Shulman, & Richert, 1987). Grossman (1985, cited in Shulman, 1987) shows that this concern is present even in new teachers who possess the substantial subject matter knowledge gained through a master's degree in a specific subject matter area, and Wilson (1992) documents that more experienced teachers have a better "overarching" view of the content field and on which to base teaching decisions.

These and other studies show that pedagogical content knowledge is highly specific to the concepts being taught, is much more than just subject matter knowledge alone, and develops over time as a result of teaching experience. What is unique about the teaching process is that it requires teachers to "transform" their subject matter knowledge for the purpose of teaching (Shulman, 1986). This transformation occurs as the teacher *critically reflects* on and *interprets* the subject matter; finds multiple ways to *represent* the information as analogies, metaphors, examples, problems, demonstrations, and/or classroom activities; adapts the material to students' developmental levels and abilities, gender, prior knowledge, and misconceptions; and finally *tailors* the material to those specific individual or groups of students to whom the information will be taught. Gudmundsdottir (1987a, b) describes this transformation process as a continual restructuring of subject matter knowledge for the purpose of teaching; and Buchmann (1984) discusses the importance of science teachers maintaining a fluid control or "flexible understanding" (p. 21) of their subject knowledge, i.e. be able to see a specific set of concepts from a variety of viewpoints and at a variety of levels, depending on the needs and abilities of the students.

Recommendations for Teachers

1. The first recommendation that can be made for teachers is for them to begin to more often reflect on or think about *why* they teach specific ideas the way they do. Teachers know much more about teaching subject matter concepts to students than they are aware. This is pedagogical content knowledge; and many teachers don't think about this knowledge as important. It is important, though, because it

determines what a teacher does from minute to minute in the classroom, as well as influencing long term planning.

To become more aware of this knowledge and to be able to more clearly think about it, teachers can find ways to keep track of this information, just as they ask students to do with the data collected in lab assignments. One way is to keep a personal notebook describing their teaching, even just once a week or so for a few difficult concepts. Another strategy is to videotape or audiotape a few class periods just to help see what's happening in the classroom. (It's not necessary to have anyone but the teacher see or listen to the tape.) Then teachers can start to think about the following types of questions. Which ideas need the most explanation? Why are those ideas more difficult for the students? What examples, demonstrations, and analogies seemed to work the best? Why did they work or not work? Which *students* did they work best *for*?

2. Teachers can try new ways of exploring how the students are thinking about the concepts being taught. Ask students about how and what they understand (not in the sense of a test, but in the sense of an interview). Ask students what "real life" personal situations they think science relates to. Try to get inside their heads and see the ideas from their point of view.
3. Start discussions with other teachers about teaching. Take the time to find someone you can share ideas with and take the time to learn to trust each other. Exchange strategies for teaching difficult concepts or dealing with specific types of students. Get involved in a peer coaching project in your school or district. District faculty development staff or people at a local university can help you get one started and may be able to provide substitute support. Ask about telephone hot-lines and computer networks for teachers, and explore the world wide web.
4. Get involved in action research projects. Much of the newestM and most important research is being conducted by teachers. Take a class at your nearest university and find out what is going on. Get involved with a mentor teacher program or a teacher on special assignment program. Join organizations and go to conferences such as the national or regional National Science Teachers Association or the National Association for Research in Science Teaching meetings. There are also often summer workshops and institutes in specific fields in science at many universities and colleges.

Where Should We Go From Here?

Contemporary research has focused on how to describe teachers' pedagogical content knowledge and how it influences the teaching process. We have yet, however, to fully understand the four components of this model, and we have yet to clearly understand how they really develop. We also know very little about how to enhance pedagogical content knowledge in preservice and inservice programs. Teacher involvement in research and university preparation programs is crucial for the development of this important idea and its usefulness for the improvement of science teaching.

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