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ABSTRACT

This paper describes the analysis of teacher pedagogical content knowledge for the topics of heat, energy, and temperature. The results of the study of these (n=6) 7th and 8th grade teachers indicate that teachers may be weak in this type of knowledge despite their experience and pedagogical expertise. Specific information is provided about existing and desired pedagogical content knowledge for this topic area, thereby identifying knowledge that can help teachers be more effective at facilitating the development of scientific knowledge, and alerting teacher educators to possible areas of weakness. In addition, the conceptual schemes that were used to identify teacher pedagogical content knowledge provides information that can be useful for conceptually framing analyses of this type of knowledge for other areas which is of immediate advantage to researchers, and of eventual benefit to teachers and teacher educators as this type of knowledge is catalogued and shared. Teacher reports of their instruction indicate that the knowledge evident in their interview was not necessarily employed in their teaching. This discrepancy indicates that the complexity of how teacher knowledge translates into instructional actions and points to the need for investigation of teacher knowledge and decision-making in all phases of teaching. (Author/MKR)

Teaching Complex Subject Matter in Science: Insights from an Analysis of Pedagogical Content Knowledge

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Abstract

This paper describes the analysis of teacher pedagogical content knowledge for the topic of heat energy and temperature. The results indicate that teachers may be weak in this type of knowledge despite their experience and pedagogical expertise. Specific information is provided about existing and desired pedagogical content knowledge for this topic area, thereby identifying knowledge that can help teachers be more effective at facilitating the development of scientific knowledge, and alerting teacher educators to possible areas of weakness. We argue that such information is useful to teacher educators for planning and implementing preservice as well as inservice instruction (Krajcik & Borko, 1991). In addition, the conceptual schemes that were used to identify teacher pedagogical content knowledge provides information that can be useful for conceptually framing analyses of this type of knowledge for other areas which is of immediate advantage to researchers, and of eventual benefit to teachers and teacher educators as this type of knowledge is catalogued and shared. A limitation of this study was that teacher PCK was not assessed in the context of all the phases of teaching: planning, interactive teaching, and reflection. Teacher reports of their instruction indicate that the knowledge evident in their interview was not necessarily employed in their teaching. This discrepancy indicates the complexity of how teacher knowledge translates into instructional action, and points to the need for investigation of teacher knowledge and decision-making in all phases of teaching.

Introduction

As recently as the mid-1980s, Shulman (1986) identified content knowledge as the "missing paradigm" in research on teaching. That statement indicated that despite volumes of research on the relationship between teaching and learning, very little was known about how content-specific teacher knowledge was related to the *instruction* conducted by teachers or the *knowledge* developed by their students. Subsequently, research has established that the content-specific knowledge used in teaching influences both the process and content of instruction (e.g., Bellamy. 1990; Carlsen, 1988; Hashweh, 1986; Sanders, 1990; Smith & Neale, 1989). At the same time, research of this nature has only been conducted in a few topic areas, and it has not yet been specified in relation to student knowledge development. That is, we do not know what content-specific teacher knowledge is *necessary* to conduct instruction to help students construct desired scientific knowledge. The work described in this paper examined content-specific teacher knowledge for the topic of heat energy and temperature, an area in which we know a lot about student understanding but little about teacher knowledge. Frameworks for describing content-specific knowledge were developed bearing in mind issues that have been identified as problematic for students.

The study described in this paper was part of a research effort associated with a large teacher enhancement project – UMMP Project[1] – which enabled experienced teachers to use specific instructional materials to help students develop scientific knowledge of heat energy and temperature. One goal of the research about the project was to describe the knowledge teachers used to help make heat energy and temperature concepts comprehensible to their students. This represents a type of content-specific knowledge used in teaching that is commonly referred to as pedagogical content knowledge. Pedagogical content knowledge has not been universally accepted as a separate domain of teacher knowledge (AERA Symposium of Grossman, Tom, Stengel, & Kennedy, April 1992; NARST Symposium of Gess-Newsome, Carlsen, Krajcik, & Lederman, April 1991), but we have argued that it is an important construct for describing the role of teacher knowledge in facilitating student knowlege development, particularly for complex subject matter such as science (Borko, 1991; Borko & Putnam, in press; Krajcik & Borko, 1991). In this paper we provide specific information about pedagogical content knowledge for heat energy and temperature, and discuss the utility of that knowledge for understanding how teacher knowledge may affect practice and desired student knowledge development. We also discuss the possible role this type of knowledge plays in conducting effective science teaching, and preparing knowledgeable science teachers.

Theoretical Framework

Teacher Knowledge

Our thinking about teacher knowledge is consistent with the perspective of Lee Shulman and his colleagues (Grossman, 1990; Marks, 1988; Wilson, Shulman, & Richert, 1987; Shulman, 1986, 1987) that describes seven domains of knowledge that teachers draw upon in planning and conducting instruction (Wilson, Shulman, and Richert, 1988). In this paper we focus on one of the domains in the Shulman scheme, pedagogical content knowledge (Shulman, 1986). This is the knowledge that teachers have of how to help students learn *specific* content, and it represents the translation or transformation of specific content knolwedge into knowledge that is useful in helping students comprehend and construct specific conceptual understandings. This knowledge distinguishes the pedagogue from the content specialist (Shulman, 1987), and it is specifically linked to classroom practice in its relationship to teacher decision-making about the *focus* and *content* of instruction (e.g., Hashweh, 1987; Bellamy, 1990).

Pedagogical Content Knowledge

Pedagogical content knowledge has been further defined as consisting of five components: (a) knowledge of alternative [content] frameworks for thinking about teaching a particular [topic], (b) knowledge of student understanding and lay conceptions[2] for a [particular topic], (c) knowledge of topic-specific pedagogical strategies, (d) knowledge of particular content, and (e) knowledge of curriculum (Shulman and Grossman, 1988, pp. 19-21). In this study we have focused on the first three components of pedagogical content knowledge: content frameworks, student understanding, and topic-specific strategies.

Content frameworks. This component of pedagogical content knowledge refers to the knowledge teachers have and use in framing chunks (e.g., units) or even a whole year of instruction. The BSCS biology programs represented by the green, ecologically-oriented; yellow, phylogentically-oriented; and blue, evolutionarily/biochemically-oriented versions of that curriculum are a case in point where a whole year of instruction is guided by a particular frame. The Introductory Physical Science (IPS) curriculum is another example as are similar products of the curriculum development of the 1960s. Whereas this type of teacher knowledge does not assume a frame of that magnitude, the point of it is to recognize that there are multiple ways to situate concepts, and that it is teachers who sometimes make the choice of how to situate concepts.

Teacher knowledge of this type would be used to make decisions about what concepts are highlighted and how they are represented in comparison to other concepts. For example, Hashweh (1987) reported two frameworks that were used by physics teachers to organize instruction about simple machines: a work/energy framework, and a functions-of-machines framework. In that study, non-physics teachers presented with same task of organizing instruction on the topic did NOT exhibit a framework or they used an inaccurate framework[3] from the resource materials they were given. This result suggests that teachers are not equally knowledgeable about frameworks for organizing instruction, and that a lack of knowledge can lead to inappropriate choices. Another possibility not mentioned by Hashweh is that in the case of several possible accurate frameworks, some may be more powerful than others in helping students develop desired scientific knowledge. In such cases, part of a teachers content framework knowledge would include information about the conceptual strength of some frameworks over others.

Student understanding. This component of pedagogical content knowledge refers to the ideas students typically have and use to build understanding in a specific conceptual area. It also refers to knowledge of the concepts that students find difficult to understand, and what it is that they find difficult. There is a rich tradition of research in science education examining student conceptions (e.g., Confrey, 1990; Driver & Easley, 1978; Gilbert & Wattts, 1983; Helm & Novak, 1983; Novak, 1987); however, little is known about what knowledge teachers have of students' lay conceptions, and how they might use that knowledge to teach effectively. Conceptual change approaches to science instruction suggest that such knowledge is important for teachers so that they can plan and conduct appropriate instruction given students' ideas (e.g., Hewson & Hewson, 1983). Knowing more about this type of knowledge and how it functions for teachers is necessary to examine that claim.

Topic-specific strategies. This component of pedagogical content knowledge refers to specific instructional strategies used by teachers to help students understand specific content. These may be analogies, laboratory activities, demonstrations, and any other information and/or activity that provide representations of specific concepts. Whereas teacher knowledge of this component has typically been differentiated by the *types* of possible strategies, specific strategies have not been evaluated with respect to how the subject matter is represented. The addition of that type of analysis would allow characterization of strategies with respect to their conceptual power.

Our focus with respect to this component of pedagogical content knowledge is on teacher knowledge of specific laboratory activities. As Brophy and Alleman (1991) argue, the activities in which students engage play an integral role in their learning. Because teachers often determine the activities in which students engage, we believe it is important to examine teacher knowledge about which activities they think are likely to help students learn specific content. Moreover, as Ball and colleagues have argued, the *representation* of subject matter in instruction is integral to the understandings students develop (Ball, 1988; McDiarmid, Ball, & Anderson, 1989). Thus, we argue that examination of this type of pedagogical content knowledge should include an evaluation of the activities based upon how the subject matter is represented.

In sum, the teacher knowledge represented by these components of pedagogical content knowledge seems clearly linked to effective science teaching to facilitate student knowledge development. Whereas it seems dependent upon content knowledge, we argue that this knowledge is different from content knowledge in distinct ways that would not be evident from examining teacher content knowledge alone. Identifying this knowledge, and determining which knowledge of this type is useful in facilitating desired knowledge development for students is an important and neglected domain of research that can help improvie science teaching.

Methodology

Participants and Context

This study was part of a large teacher enhancement project entitled the "University of Maryland Middle School Probeware Project" (UMMP Project) which helped teachers use microcomputer-based laboratory (MBL) activities to improve their teaching about heat energy and temperature (Layman & Krajcik , 1987). Teachers in the study sample were all members of the Advanced Group of UMMP Project teachers, a designation that signified when a teacher became involved in the Project. Teachers in the Advanced Group (N=13) participated in workshops in each of two consecutive summers, as well as periodic meetings during the school year.

All Project teachers (N=22) were selected for their initial participation in the UMMP Project by their school districts' science supervisors on the basis of the following criteria: (a) having an active middle school program, (b) possessing leadership qualities, and (c) having access to microcomputer-based laboratory hardware and software during the school year. Components of the UMMP Project teacher enhancement effort included two intensive, three-week summer workshops held in consecutive years[4], periodic meetings for teachers during the school year to discuss the progress of the Project and share teaching successes and challenges, and classroom assistance for teachers who requested help during their microcomputer-based laboratory activities. The workshops focused on the use of MBL activities for instruction about heat energy and temperature and on the development of activities that were specific to each teacher's curriculum. These activities became the basis of instruction about heat energy and temperature for the middle school teachers during the school year.

The participants in this study were from a group of teachers who were randomly-selected to participate in the research component of the Project. By the second year of the Project, only seven teachers from the thirteen who were selected for the research component had participated in *both* summer workshops *and* had teaching situations in which they used MBL activities to teach heat energy and temperature concepts for the two years of the project . Of those seven teachers, six comprise the sample in this study.[5] Those six teachers were from two districts surrounding a large, eastern city; taught at the 7th or 8th grade level in the area of physical or earth science; had from 7 to 24 years of teaching experience; and had all taught their current curriculum for at least five years. Thus, the teacher participants were experienced, knowledgeable and committed teachers.

Data Collection and Sources

Information about teacher pedagogical content knowledge (PCK) was obtained through teacher interviews conducted at the beginning and end of the school year, prior to and following each teacher's instructional unit on heat energy and temperature during the second year of their involvement in the Project. The interviews consisted of a open-ended and problem-solving tasks presented to participants. The open–ended task, a series of questions about the concepts of heat energy and temperature, elicited general information about participants' PCK associated with understanding the relationship between heat energy and temperature. The problem-solving task, a hypothetical situation involving heat energy transfer, provided information about teachers' PCK related to factors influencing heat energy transfer. Figure 1 shows the context of the problem-solving task, and an example of a student's response to the task of drawing a cooling curve to represent the situation.

In each task, information about each teacher's PCK was obtained by asking questions in which teachers were expected to identify : (a) what conceptual understandings they expected their students to use in responding to a task, (b) what their students would predict and how their students would reason about the heat energy phenomena they were asked to interpret, (c) what reasoning might have led a student to a particular response [graph in Figure 1][6], and (d) what they (the teachers) would do instructionally to help their students develop the desired scientific knowledge required to accurately respond to the tasks.

Interviews were conducted on an individual basis, typically during a teacher's planning period, and props in addition to diagrams were used when possible to illustrate the hypothetical problem-solving situations presented during the interview. The interviews were semi-structured; that is, they all contained the same basic set of questions but extensive probing occurred to elicit elaboration or explanation of a response, to achieve greater clarity and understanding of the teacher's understanding. The interview protocols used were those of the UMMP Project (Krajcik & Layman, 1989). Exact protocols of the interviews are contained in Magnusson (1991).

Data Analysis

Interviews were transcribed for analysis, and the following procedures were employed to conduct the analysis. First, the transcripts were subjected to a data reduction process in which sections of text that included information about the teachers' pedagogical content knowledge were marked, and coded with respect to the components of PCK represented. As indicated previously, the interview elicited information about teacher knowledge related to three components of pedagogical content knowledge: content frameworks, student understanding and lay conceptions, and topic-specific pedagogical strategies. The second step was a form of propositional analysis similar to that employed by Pines (1977, described in Posner & Gertzog, 1982) in which a set of statements that described each component of each teacher's knowledge was compiled from each interview. The third step was to develop a classification scheme with respect to each component so that each teacher's knowledge could be evaluated and compared to that of the other teachers. The classification schemes for each component were developed differently and are discussed below.

Content framework (CF). The categories used to classify teachers' knowledge with respect to this component were determined in two ways. First, teacher statements were differentiated on the basis of whether they represented the concepts microscopically or macroscopically – a common scheme for differentiating frameworks for some science topics. Second, in the macrosopic category, an analytic approach akin to domain analysis (Spradley, 1980) was employed to generate specific frameworks from the propositions which indicated each teacher's knowledge of this component. A domain analysis is useful for differentiating propositions on the basis of the semantic relationships contained in the proposition (e.g., function, cause-effect, class inclusion). In this case, the propositions reflected different types of relationships between heat energy and temperature. A reliability check for this analysis was conducted on a portion of the data with the help of another researcher knowledgeable about pedagogical content knowledge. Reliability was at the level of agreement on judgements of which frameworks were exhibited by each teacher. Inter-rater agreement was 87%, and disagreements were settled by mutual consent.

Student understanding and lay conceptions (SU). The classification scheme for this component of pedagogical content knowledge was developed using information from previous research, including analyses of other data from the UMMP Project (Krajcik & Layman, 1989). It included establishing whether teachers were knowledgeable about common lay conceptions in this topic area, as well as common reasoning errors made by students in interpreting or estimating experimental results. Previous research about heat energy and temperature has established that distinguishing between those concepts is historically and developmentally problematic (e.g. Wiser & Carey, 1988; Linn, Songer, Lewis, & Stern, 1991). Thus, evaluating whether teachers knew that students commonly think that temperature measures heat energy was one category for comparing teacher knowledge. This category also included other lay conceptions identified by the teachers.

A second category focused on knowledge about student errors in reasoning. Previous analyses of UMMP Project data indicated that students commonly made particular reasoning errors in interpreting heat energy transfer for beakers of water of different volumes and temperatures (Magnusson, Layman, & Krajcik, 1992), a common context for for investigating temperature and heat energy in classrooms. For example, it is not uncommon for students to state that a smaller volume of water going through the same change in temperature as a larger volume will lose more heat energy because it cools more quickly. In this category, teacher knowledge was described in terms of whether teachers knew that: (a) a specific inaccurate student response that they were shown was *in*accurate, and (b) it was a typical response for middle school students. In addition, they were evaluated with respect to whether they could provide an *explanation* as to why students might respond in such a fashion.

Inter-rater reliability of the analysis for this component of pedagogical content knowledge was at the level of agreement on the following judgments: (a) whether a teacher knew of a common lay conception, (b) whether a teacher identified a student response as inaccurate but typical, and (c) whether a teacher could explain a student's reasoning with respect to the (inaccurate response. Inter-rater agreement for this analysis was 100%.

Topic-specific pedagogical strategies. The categories used to evaluate teachers' knowledge of this component were determined partly by the types of teaching strategies common in classroom science instruction (e.g., laboratory activity, discussion, reading from a textbook, demonstration), and partly by logical parameters useful for distinguishing laboratory activities (e.g., independent, dependent, and controlled variables). Additional classification of laboratory activities was necessary because that type of strategy was most commonly and most specifically described by the teachers in this study, and that scheme was most useful in describing and differentiating teacher knowledge. For our purposes, the *range* of teacher knowledge, NOT the *amount*, was of most importance. Hence, a teacher who described two activities that fit the same category was not assessed as having different knowledge from that of a teacher who only described one activity in a particular category.

Inter-rater reliability was at the level of agreement on judgements of which categories were represented by the strategies described by the teachers. Inter-rater agreement was 83%, and disagreements were settled by mutual consent.

Results

Results are presented separately with respect to each component of PCK.

Content Frameworks

Description. A major contribution of this analysis was the identification of frameworks for teaching about heat energy and temperature. Four different frameworks were identified; one describing relationships at the microscopic level, and three describing relationships at the macroscopic level. The frameworks were named according to the idea that each emphasized with respect to heat energy phenomena, however, they are not mutually exclusive, and it is possible for teachers to exhibit more than one framework. The frameworks can be distinguished on the basis of how the concepts of heat energy and temperature are represented, and whether the conceptual focus of the framework is likely to challenge common lay conceptions such as the ideas that heat energy is measured by temperature and contained within a body.

Table 1 illustrates the conceptual strengths and weaknesses of each framework. Those differences make them more or less desirable for use in teaching about heat energy and temperature. Some frameworks represent the concepts incorrectly or may suggest inaccurate representations. For example, in the Energy framework, temperature is defined as energy at a particular spot within a substance (accurate), and heat energy is defined as the energy of the whole substance (inaccurate). This framework is undesirable because it promotes an inaccurate view of heat energy. in the Molecular framework, heat energy is described as influencing molecular motion (accurate), but that can be easily misunderstood as implying that heat energy *is* molecular motion (inaccurate). The Molecular framework is better than the Energy framework because it *can* communicate an accurate view of heat energy, but it is less desirable than the other frameworks because is can be interpreted in a way that promotes an inaccurate view of heat energy . The Factor and Transfer frameworks are both acceptable frameworks for teaching about heat energy and temperature, although the Transfer framework provides more of a conceptual idea of heat energy in comparison to the Factor framework. The strength of the Factor framework is that it represents heat energy in a way that is useful for quantitative problem-solving.

One aspect that sets the Factor and Transfer frameworks apart from the others is that they are both capable of challenging inaccurate knoweldge about the relationship between heat energy and temperature. In the Factor framework, the emphasis is that there are several factors used to calculate the amount of heat energy transferred in a specific situation. This perspective highlights that temperature alone does not indicate the amount of heat energy transferred; hence, rendering inaccurate the lay conception that temperature measures heat energy. At the same time, it may support the idea that heat energy is contained in a body (even though ΔT is required for the calculation, that point that can easily be lost in the focus on a numeric result). In contrast, the Transfer framework specifically defines heat energy as the type of energy that is *transferred* when there is a difference in temperature. This framework emphasizes that heat energy is *not* contained in a body (accurate), but is transferred between bodies at different temperatures. While that is beneficial, the Transfer framework may also support the idea that temperature measures heat energy (inaccurate) because it focuses on temperature and not on other variables that impact a situation if the *amount* of energy transferred is on interest. As a result, both of these frameworks emphasize important and accurate information about heat energy and temperature, but they differ in the inaccurate knowledge that they can challenge.

This conceptual scheme indicates that the Factor and Transfer frameworks are logically superior frameworks for teaching about heat energy and temperature at the middle school level. The study was not extensive enough to empirically confirm the instructional advantage of these frameworks, but such investigation is a logical next step. What these results do provide is a strong argument for the utility of examining the frameworks that teachers use in helping students make sense of complex concepts. Furthermore, if we are able to identify conceptual advantages of specific frameworks, that will be important knowledge to share in preparing effective science teachers.

Teacher Knowledge. Table 2 shows the results of the analysis of teacher knowledge for this component of pedagogical content knowledge. A framework described by one teacher did not fit any categories because it did not distinguish between heat energy and temperature; hence, it was placed by itself. The results indicate that although there was some change across the interviews for most of the teachers, all but one of the teachers exhibited a consistent framework in both interviews. There was not a dominant framework that was consistently exhibited by the teachers. The interview did not probe thoroughly with respect to this component of pedagogical content knowledge, and further investigation is neede to determine whether there were dominant frameworks for a teacher and to what extent multiple frameworks guided instructional decisions.

In addition, the results for one of the teachers, Ms. Mason, are striking because of the great degree of difference between the framework she exhibited at the beginning of the year prior to her instruction, and the knowledge she exhibited at the end of the year long after her instruction in this topic was complete. She was unique in exhibiting only *one* framework in each interview, and the framework she exhibited in the spring interview is inaccurate, and represents heat energy in a way that matches a common lay conception. This means that she changed from exhibiting a desireable framework to one that was undesirable because of its inaccuracies. We found this change surprising, and it raises questions about the stability of teacher pedagogical content knowledge.

Student Understanding and Misconceptions

Results from the analysis of this component of pedagogical content knowledge are shown in Table 3. With respect to teacher knowledge of lay conceptions, all the teachers were aware of the lay conception that temperature measures heat energy, a result that is not surprising because that information was emphasized during the workshops in which the teachers participated. Several other lay conceptions were identified as well, however, but by only three of the teachers. In the fall interview, Ms. Baxter indicated that students think that heat energy is the motion *in* molecules rather than the motion *of* molecules, neither of which is accurate. In the spring interview she described a different lay conception: that students think that objects which are used to keep things warm possess heat energy themselves. Ms. Carlson also noted an additional lay conception in her fall interview. She discussed that students inappropriately stated that differences in the distance to a heat source (specifically, variation in the height of bunsen burner flames) explained the change in slope of a heating curve. Finally, Mr. Roberts noted the student lay conception that heat energy has only to do with things that are hot or being heated.

Although there was not a lot of variation in these results, we think it is significant that some teachers were able to provide specific *additional* information about ideas that students have that are contrary to scientific knowledge With the exception of the molecular motion idea, the lay conceptions are associated with instructional activities conducted by these teachers. Thus, they represent teacher knowledge of the ways students construct understanding of their experiences, albeit in ways that are unfortunately contrary to desired scientific knowledge. Although it is not clear what impact this knowledge had on their instruction, it is logical to think that teachers with this type of knowledge might be more likely to have students describe their thinking so that they (the teachers) can check to see how the students are constructing understanding. This same issue is relevant to the results discussed next.

With respect to the other aspect of this component of pedagogical content knowledge, the issue of student reasoning about heat energy phenomena, there was much greater variation in teacher knowledge among the teachers in this study. First, although the teachers look identical in terms of their knoweldge about students' reasoning that volume does not make a difference (column 4 of the table), there were some differences in the explanations that teachers provided about why students would reason in that way. Basically, teachers explained that the students focused on temperature. Differences occured in that some teachers indicated that students focused on the similarity in *starting* temperature, or they said students focused on the temperature *change*.

Greater differences occured among the teachers with respect to their knowledge of student reasoning errors when students indicated that a *smaller* volume lost more heat energy than a larger volume. One major difference among the teachers was that some thought this was an unlikely response. Analyses of student data from these and other teachers' classes (Magnusson, 1991; Magnusson, Layman, Krajcik, 1992) indicated that it was NOT an unlikely response. About 30% of the students who participated in the study gave this response, and two of the three teachers (Ms. Gentry and Ms. Mason) who indicated it was an unlikely response had students in their classes who gave that response (Magnusson, 1991). Only Ms. Carlson had NO students who gave that response.

This result suggests that teachers may lack sensitivity to some common reasoning errors made by their students. Previous research in other areas (mathematics) has shown that teacher knowledge of their students' knowledge is an important predictor of student achievement (Peterson, Carpenter, Fennema, 1989). It stands to reason that a teacher's lack of knowledge about this typical reasoning error may mean that he or she would be NOT be as likely to check how students were reasoning about volume, as someone who was knowledgeable. Furthermore, teachers lacking this knowledge may NOT consider it important to provide opportunities for students to discuss their reasoning. In such cases, providing teachers with information about common errors in student reasoning may persuade them that it IS important to have students discuss their reasoning.

With respect to explaining why students might reason in this way, teachers differed in being able to provide an explanation, and they differed in the explanations that they provided. Ms. Carlson was unique in that she was the only teacher who thought the response that the smaller volume lost more heat energy was <u>un</u>likely, but she could still provide an explanation for why students would reason in that way. The other teachers who thought it was an <u>un</u>likely response could NOT give an explanation. All of the teachers who thought it was a <u>likely</u> response could give an explanation.

There were three types of explanations that teachers provided. Ms. Carlson thought that it was possibly a misinterpretation of the question. If not that, she thought that students thought quickness was important and that because the water cools faster it loses more heat energy. She stated that students equate faster with more because "if you go faster you can get more done. Like if you're driving faster you can travel a larger distance. They don't understand that [the rate of temperature change] slows down, or that it reaches a point where it doesn't change" [TF89202A:363-365]. Ms. Baxter and Mr. Roberts gave similar responses, but Mr. Roberts raised an additional point. He said that "[the students] might answer [the smaller volume] because it would cool faster and give up more energy. That's a typical way of thinking that students will respond because [the water in the smaller volume] is cool while the other one is still hot" [TF89301B:143-147]. He went on to talk about how students do not understand about the water cooling to room temperature and coming to equilibrium with the surroundings. This explanation is significantly different from that described by Ms. Carlson because it adds another concept to the issue of how students are reasoning in this situation. If the issue is just about cooling quickly, it is important to have students discuss that the rate of cooling and the amount of time to cool are different variables and must *both* be considered in reasoning about the amount of heat energy transferred. If there is also a concern about understanding that systems are driven toward equilibrium, and that the beakers of water are driven to reach equilibrium with the temperature of the room, that involves other concepts as well.

This result points to the importance of examining pedagogical content knowledge because the explanation provided by Mr. Roberts implies a different instructional response to help students reason more appropriately. Asking teachers to provide an explanation for inaccurate student responses was useful in differentiating the teachers' on the basis of their knowledge, and provided information about student reasoning that can help other teachers understand important issues in student knowledge development.

Topic-Specific Pedagogical Strategies

Teacher knowledge of this component of pedagogical content knowledge is shown in Table 4. These results indicate that there were substantial differences among the teachers with respect to their knowledge of strategies when considering those which highlight the distinction between heat energy and temperature. Because a major issue in developing scientific understanding of heat energy and temperature is understanding the difference between the concepts, instructional strategies highlighting the difference are expected to be most effective in helping students develop accurate understanding of heat energy phenomena. Thus, TSS categories were classified with respect to whether an activity fitting that category emphasized the distinction between heat energy and temperature. Then, the TSS knowledge of teachers was compared with respect to *all* the strategies they described as well as the special class of strategies which emphasized the distinction between heat energy and temperature.

What this representation of teacher knowledge revealed was that the most of the teachers did NOT exhibit substantial knowledge of activities that emphasized the distinction between heat energy and temperature. The lack of knowledge of strategies of this type – those which emphasize the distinction between heat energy and temperature – is surprising because the phrasing of the interview questions posed to the teachers explicitly or implicitly requested that they describe what they would do to help students understand the distinction. One explanation for this result is that the teachers' knowledge was impoverished in this respect. Another explanation is that the teachers' framework for organizing their knowledge did not include categorization based upon emphasizing the distinction; rather, it was organized by whether an activity dealt with mainly with temperature or mainly with heat energy, and was not very differentiated beyond that. Because the distinction between heat energy and temperature is a critical feature of this subject matter (Wiser & Carey, 1983), the lack of organization along this dimension may be evidence of under-developed knowledge for these teachers, despite their experience and expertise. Thus, this analysis identified an important dimension of TSS knowledge for this subject matter.

Summary and Significance

This paper describes the analysis of teacher pedagogical content knowledge for the topic of heat energy and temperature. Results of these analyses indicate that teachers vary in a number of ways with respect to the topic-specific knowledge they use in teaching specific subject matter. Moreover, even though the teachers in this study were experienced, and had been judged as having sufficient expertise to be recommended for the Project, they were not equally knowledgeable with respect to how to help students comprehend the subject matter. The conceptual schemes used to identify teacher pedagogical content knowledge for this topic provide information about which knowledge is conceptually desireable, although empirical evidence for its desireability was not provided. Thus, for those teachers who lack pedagogical content knowledge, the schemes identify some of the knowledge or attributes of it that teachers need to gain to be more effective at helping students develop scientific knowledge.

This finding is important in informing the discussion about the usefulness of pedagogical content knowledge as a construct. The results presented in this paper would not typically be identified in an exploration of teacher content knowledge for this topic, and yet, the knowledge is clearly important in teacher thinking about learning and instruction in this area. We recommend that this line of work continue and be expanded to many content areas. We would argue that not only will the information gained from this and related work benefit practicing teachers as they strive to become more effective science teachers, and to teacher educators who work with them, but also that it is useful to teacher educators for planning and implementing instruction at the preservice level (Borko, 1991; Borko & Putnam, in press). We believe that this dimension of teacher knowledge is important to consider as a major focus of methods courses at the pre-service level. If an important thrust of current educational efforts is to prepare teachers to teach for understanding, insights about pedagogical content knowledge provide important information for helping prospective teachers become knowledgeable in ways that will help them help their students construct desired understanding.

Finally, a limitation of the study was that teacher pedagogical content knowledge was not assessed in the context of all the phases of teaching: planning, interactive teaching, and reflection. Teacher reports of their instruction (Magnusson, 1991), for example, indicate that their TSS knowledge did not necessarily correspond to the strategies they used in their teaching. This discrepancy indicates the complexity of how teacher knowledge translates into instructional action, and further points to the need for investigation of teacher knowledge and decision-making in all phases of teaching. This is a neglected area of research, and one that we believe is important to developing a teaching workforce that can support the conceptual development of all of our students.

END NOTES

[1] UMMPP stands for the "University of Maryland Middle School Probeware Project." This project involved middle school science teachers in intensive introductory and advanced summer workshops as well as periodic meetings during the school year to prepare and support them in conducting instruction using microcomputer-based technology. The project was funded by the National Science Foundation under Grant No. TPE 8751744. Any opinions, findings, and conclusions or recommendations expressed in this paper are those of the authors and do not necessarily reflect the views of the National Science Foundation.

[2] This term, developed by Magnusson, Boyle, and Templin (1994), refers to knowledge held by learners that differs from accepted scientific knowledge, but we use this term rather than misconceptions to indicate that this knowledge has utility for the individual and is used for explanatory purposes. This idea is similar to what has been referred to as childrens' science (Osborne, Bell, & Gilbert, 1983); however, our choice of terminology is intended to reflect that these conceptions are common among individuals of all ages, and that they differ from scientific knowledge because the norms for generating scientific knowledge are not common to the generation of knowledge for individuals in everyday life.

[3] Systems help make work easier because they allow a gain in force, and the types of systems are ramps, levers, pulleys, and gears. (p. 114)

[4] The workshops included the following elements: (a) discussion of the nature of student learning, especially with respect to the construction of knowledge, (b) discussion of theory and research describing the benefits of using microcomputer-based laboratory (MBL) activities, (c) practice using microcomputers and conducting MBL activities, and (d) modifying and creating MBL activities for heat energy and temperature.

[5] One teacher was dropped because of missing data due to unknown technical problems during the taping of interviews.

[6] In each case, the student response shown to a teacher represented a common, inaccurate response to a typical problem involving heat energy and temperature phenomena.

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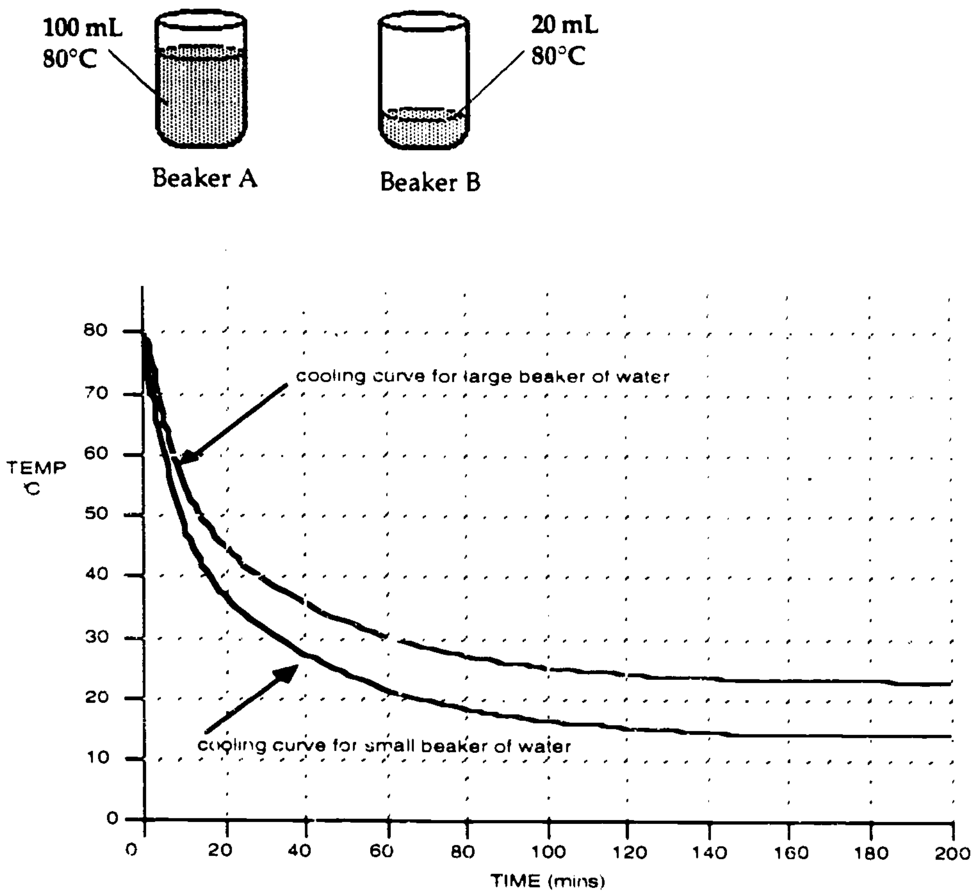

Figure 1. Problem-solving Task: physical situation, and student prediction of the graphical result if the water were allowed to cool to room temperature.

Table 1

Content Frameworks For Teaching About Heat Energy And Temperature

	MICROSCOPIC	MACROSCOPIC		
CONTENT	Heat energy is associated with molecular motion.	T is one factor influencing HE.	HE is the energy of the whole; T, is the energy of a part.	HE is energy transfer associated with a ΔT.
Framework Name	Molecular Framework	Factor Framework	Energy Framework	Transfer Framework
Accurate representation of Heat Energy?	YES, but misleading	YES	NO	YES
Accurate representation of Temperature?	does not describe	does not describe	YES	does not describe
Accurate representation of relationship bet. HE & T?	NO	YES	NO	YES
Can challenge inaccurate knowledge?	NO	YES	NO	YES

Table 2

Teachers' Content Frameworks for Teaching About Heat Energy and Temperature

		MICROSCOPIC	MACROSCOPIC			
	INTV.	Molecular Framework	Factor Framework	Energy Framework	Transfer Framework	OTHER
Ms. Baxter	F	√	√			
	S	√		√		
Ms. Carlson	F	√			√	
	S				√	
Ms. Gentry	F			√	√	T gives an idea of the HE in a system
	S	√		√		
Ms. Lowry	F		√			
	S	√	√			
Ms. Mason	F		√			
	S					HE is energy, T tells how much
Mr. Roberts	F		√		√	
	S		√		√	

Table 3

Teacher Knowledge of Student Understanding

		Student Lay Conceptions		Student Reasoning about Heat Energy Phenomena: Ignore Volume Differences in a Heat Energy Transfer		Student Reasoning about Heat Energy Phenomena: Smaller volume loses more Heat Energy in a Transfer	
	Intv. Date	Temp. meas. HE	Other	Common response?	Explained Student Reasoning	Common response?	Explained Student Reasoning
Ms. Baxter	F	√	1	yes	yes	yes	yes
	S	√	1	yes	yes	*	*
Ms. Carlson	F	√	1	yes	yes		yes
	S	√		yes	yes	not likely	yes
Ms. Gentry	F	√		yes	yes		
	S	√		yes	yes	not likely	
Ms. Lowry	F	√		yes	yes		
	S	√		yes	yes	yes	yes
Ms. Mason	F	√		yes	yes	not likely	
	S			yes	yes		
Mr. Roberts	F	√	1	yes	yes	yes	yes
	S	√		yes	yes	yes	yes

√ Indicates that the teacher exhibited the designated knowledge

* Probing of this teacher stopped after the first response was given; hence, the teacher was not afforded the same opportunity as the others to exhibit this knowledge.

Table 4

Teachers' Knowledge of Pedagogical Strategies for Teaching About Heat Energy and Temperature

Topic-Specific STRATEGIES (TSS)	TEACHERS											
	Baxter		Carlson		Gentry		Lowry		Mason		Roberts	
Laboratory Activities	F	S	F	S	F	S	F	S	F	S	F	S
VOLUME vs. Time	√			√	√	√	√		√			
vs. *ΔHeat Energy*		√̲	√̲	√̲	√̲	√̲		√̲		√̲		
vs. *ΔTemperature*		√̲	2̲	√̲	√̲		√̲	√̲				
MASS vs. *ΔTemperature*	√̲	√̲									√̲	√̲
MATERIAL vs. *ΔTemperature*			√̲						√̲	√̲		
ΔHEAT ENERGY vs. ΔTemperature		√						√				
PHASE CHANGE – *NO ΔTemperature*				√̲				√̲				
Textbook Readings			√	√					√	√		
Discussion	√				√	√	√					
Other			1				1[a]		1		≥2̲	≥2̲
TOTAL number of strategies.	3	4	6	5	4	3	6	5	4	3	≥2	≥2
TOTAL number of strategies emphasizing the distinction between HE and T.	**1̲**	**3̲**	**4̲**	**3̲**	**2̲**	**1̲**	**1̲**	**3̲**	**1̲**	**2̲**	**≥2̲**	**≥2̲**

Key:

- • The activity described emphasized the distinction between HE and T
- √ The teacher described an activity which matched the activity type
- ? Number of activities was unspecified but several were implied, they may or may not have been of a different types.

HE Heat energy
T Temperature
Δ Change in

[a] Not enough information was provided to determine whether the named activity emphasized the distinction between heat energy and temperature.