DOCUMENT RESUME

ED 387 313 SE 056 557

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TITLE Teacher Knowledge and Representation of Content in Instruction about Heat Energy and Temperature.

PUB DATE Apr 93

NOTE 21p.; Paper presented at the Annual Meeting of the National Association for Research in Science Teaching (Atlanta, GA, April 1993).

PUB TYPE Reports - Research/Technical (143)

EDRS PRICE MF01/PC01 Plus Postage.

DESCRIPTORS Energy; *Heat; Instructional Design; Interviews; *Knowledge Base for Teaching; *Knowledge Representation; Science Curriculum; Science Instruction; *Science Teachers; *Scientific Concepts; Secondary Education; Teacher Education; *Temperature

IDENTIFIERS Microcomputer Based Laboratories

ABSTRACT

Pedagogical content knowledge, the content-specific knowledge which embodies the aspects of content most germane to its teachability and which is most likely to distinguish the understanding of the content specialist from the pedagogue, has been widely regarded as important for effective teaching of complex subject matter such as science. This paper focuses on one aspect of pedagogical content knowledge, topic-specific pedagogical strategies, and describes a framework for categorizing the strategies on the basis of how the subject matter is represented. The research was conducted in the context of a large teacher enhancement project which enabled experienced teachers to use microcomputer-based laboratories to help students develop scientific knowledge of heat energy and temperature. The conceptual analysis undertaken in this study demonstrates the utility of a conceptual analysis of instructional activities with respect to representation of content, allows comparison of instructional activities that may be very different contextually, and may provide a framework for conceiving new activities that are powerful representations of the content. Results indicate that teachers did not appear to have differentiated knowledge of instructional tasks with respect to the distinction between heat energy and temperature. Implications for teacher preparation are also discussed. (Contains 31 references.) (JRH)

ED 387 313

Teacher Knowledge And Representation Of Content In Instruction About Heat Energy And Temperature

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April 1993

Paper presented at the 1993 annual meeting of the *National Association for Research in Science Teaching*, Atlanta, GA.

As recently as the mid-1980s, Shulman (1986) identified content as the "missing paradigm" in research on teaching. Subsequent work by a number of researchers interested in teacher knowledge was aimed at distinguishing and identifying the content-specific knowledge used in teaching. Of particular importance has been the content-specific knowledge which "embodies the aspects of content most germane to its teachability" (Shulman, 1986, p. 9) and which is "most likely to distinguish the understanding of the content specialist from that of the pedagogue." (Shulman 1987, p. 8) Shulman and his colleagues have called this knowledge *pedagogical content knowledge* (Grossman, 1990; Marks, 1988; Wilson, Shulman, & Richert, 1987; Shulman, 1986, 1987), and it has been widely regarded as important for effective teaching of complex subject matter such as science (Bellamy, 1990; Carlsen, 1988; Hashweh, 1986; Magnusson, 1991; McDiarmid, Ball, & Anderson, 1989; Sanders, 1990; Shulman & Grossman, 1988; Smith & Neale, 1989). Ball (1988) has emphasized that the critical aspect of *pedagogical content knowledge* is the representation of subject matter. In a paper elaborating that idea, McDiarmid, Ball, and Anderson (1989) state that "the instructional representations that students encounter *define* [emphasis added] their formal opportunities for learning about the subject matter." (p. 194) This perspective suggests that representation is an important focus for examining pedagogical content knowledge for science teaching. The purpose of this paper is to discuss such knowledge for teaching about heat energy and temperature.

Theoretical Framework

Shulman and his colleagues have described a logical framework for teacher knowledge that consists of seven domains of teacher knowledge (Wilson, Shulman, & Richert, 1988). Among those domains is one type of knowledge that is newly framed – pedagogical content knowledge – and arguably best represents the knowledge that is crucial to effective teaching of complex subject matter such as science. Pedagogical content knowledge has been further described as consisting of five components (Shulman & Grossman, 1988, pp. 19-21): (a) knowledge of alternative [content] frameworks for thinking about teaching a particular [topic], (b) knowledge of student understanding and misconceptions of a [topic], (c) knowledge of particular content, (d) knowledge of curriculum, and (e) knowledge of topic-specific pedagogical strategies. Ball (1988) indicates that the *representation* of subject matter inherent in instruction is the most critical aspect of pedagogical content knowledge, and McDiarmid, Ball, & Anderson (1989) define instructional representations as "a wide range of models that may convey something about the subject matter to the learner: activities, questions, examples, and analogies." (p. 194). Ball describes *good* instructional representations as having the following attributes: (a) correct and appropriate representation of the substance and the nature of the subject being taught, (b) comprehensible to the particular pupils being taught, (c) contribute helpfully to learning, and (d) reasonable and appropriate in the context (paraphrased in McDiarmid, Ball, & Anderson, 1989, p. 197).

Taken together, Ball and her colleague's ideas are encompassed by three of the components of pedagogical content knowledge defined by Shulman and his colleagues: alternative content frameworks, student understanding and misconceptions, and topic-specific pedagogical strategies. At the same time, their formulation emphasizes the importance of differentiating that knowledge with respect to how the subject matter is repre- his is particularly at issue in science teaching because of the well-documented issue of the prior knowledge about the nature of the physical world that students bring to science instruction (Gilbert & Watts, Driver & Easley, Osborne & Freyberg, etc.) . For example, for a specific set of instructional activities, although all activities may be reasonable and appropriate, correctly represent the subject matter, and comprehensible to the students, they may vary considerably in the extent to which they are persuasive in helping students change already held conceptions (e.g. Clement, Brown, Zeitsman, 1989; Linn & Songer, 1991; Roth, 1985; Wiser & Kipman, 1988). Thus, it is not only important to identify pedagogical content knowledge for specific science topics, but it is also important to distinguish the knowledge with respect to the representations that are most powerful or persuasive in helping students build scientific knowledge.

This paper focuses on one aspect of pedagogical content knowledge – topic-specific pedagogical strategies – and describes a framework for categorizing the strategies on the basis of how the subject matter is represented. The science topic of concern with respect to teacher knowledge discussed in this paper is heat energy and temperature, with a specific focus on the distinction between those concepts. We focus on distinguishing those concepts because that is an issue that has historically (Wiser & Carey, 1983; Wiser, 1988) and practically (Linn, Songer, Lewis, & Stern, in press) been problematic. The research questions we asked were: (a) what is a useful conceptual framework for analyzing pedagogical strategies with respect to how they represent the content, and (b) how do the strategies that teachers describe as useful compare to the strategies they actually used, with respect to the representation of the subject matter?

Methodology

This work was conducted in the context of a large teacher enhancement project – UMMPP[1] – which enabled experienced teachers to use microcomputer-based laboratories to help students develop scientific knowledge of heat energy and temperature (Layman & Krajcik, 1987). The goals of the project were to familiarize teachers with the hardware and software for conducting instruction using microcomputer-based laboratories, and support the development of curricula for teaching about heat energy and temperature using microcomputer-based laboratories. The teachers were selected for participation on the basis of recommendations from their school districts, and Table 1 shows their teaching experience and the context of their instruction. The research associated with the project included examination of teacher content and pedagogical content knowledge.

Data Collection

Interview transcripts serve as the sole data source in this study. Six teachers who were originally randomly-selected to participate in the research portion of the UMMPP, and who continued with the project for its duration comprise the sample for this study. Teachers were interviewed in the fall and spring of each year of the project, and the data in this study were from interviews conducted during the second school year during which the teachers used microcomputer-based laboratories for their instruction about heat energy and temperature. The interviews were semi-structured and consisted of a series of tasks presented to participants: an open-ended task and three problem-solving tasks.[2] To elicit pedagogical content knowledge about topic-specific pedagogical strategies, in each task the teachers were asked what they would do in their teaching to help students gain a better understanding of the concepts in the tasks with which they were presented. In the spring interview, teachers were also asked to describe the instructional activities that they had used during their instruction about heat energy and temperature.

Data Analysis

Knowledge of strategies. Teacher knowledge of topic-specific pedagogical strategies was identified by coding the interview for any information provided by the teachers with respect to how they would or did help the students understand the distinction between heat energy and temperature. The second step was to reduce the data to a set of statements from each interview containing the relevant descriptions of strategies the teachers described, and to sort the strategies with respect to types of instructional activities (e.g., discussion, laboratory activities). Laboratory activities comprised the vast majority of strategies described, and a third step in the analysis was to develop a classification scheme to evaluate the representation of the content in each laboratory activity.

The framework used to differentiate content representations in the laboratory activities was derived partly from by logical parameters useful for distinguishing laboratory activities (e.g., independent, dependent, and controlled variables), and partly from research indicating a central conceptual issue in understanding heat energy and temperature is the ability to appropriately distinguish between those concepts (Wiser & Carey, 1983; Wiser, 1988). The framework we developed contains nine categories for distinguishing the laboratory activities on the basis of identifying the independent, dependent, and controlled variables. For example, an activity in which students measure the time it takes for two different volumes of water to go through the same temperature change (e.g., 50°C to 25°C), has the following basic elements: (a) volume is the independent variable, (b) time is the dependent variable, and (c) change in temperature is the controlled variable. A similar activity in which students calculate the amount of heat energy lost by two different volumes of water at the same starting temperature cooling to room temperature, has the following basic elements: (a) volume is the independent variable, (b) change in heat energy is the dependent variable, and (c) change in temperature is the controlled variable. Figure 1 shows the categories used to evaluate the content representation in laboratory activities described and used by the teachers.

The categories of laboratory activities were also distinguished on the basis of whether they emphasized the distinction between heat energy and temperature. This was determined on the basis of the relationship between the variables describing a category. Categories that emphasized the distinction included one of the following elements: (a) the amount of heat energy changed but temperature did not (e.g., in a change of state), (b) a change in heat energy resulted in different changes in temperature (e.g., adding the same amount of heat energy to the same masses of different substances), and (c) the amount of heat energy transferred was calculated from measurements of the necessary variables (e.g., volume and temperature change if comparing heat energy transferred to the environment when two volumes of water cool to room temperature from the same initial temperature). A category did not emphasize the distinction between heat energy and temperature if a change in temperature and heat energy transfer were similar and there was not measurement of the amount of change to compare them. For example, the transfer of the same amount of heat energy from two different volumes of water cooling from 45°C to 22°C would not result in the same amount of heat energy transfer, and that would be evident in the different amounts of time to cool; however, the inference from time is not readily apparent because students can attribute the time difference to other factors such as the "ease" with which heat energy can "escape" from the smaller volume in comparison to the larger. Thus, students can come to the conclusion that the time difference has nothing to do with the amount of heat energy transferred.

Using the above criteria, it was determined that five of the nine categories represented activities that included elements emphasizing the distinction between heat energy and temperature. In Figure 1, those categories are 2, 3, 4, 7, and 9. Those categories are in italicized type in the figure.

The knowledge exhibited by each teacher was evaluated by comparing the features of each activity described by a teacher to the features of the categories as shown in Figure 1. We were interested in the range or differentiation of teacher knowledge rather than the "amount," so, when a teacher described several activities matching the same category, that teacher was characterized only as exhibiting knowledge fitting that category. We did not try to quantify the amount of knowledge exhibited with respect to a category.[3]

Inter-rater reliability of this analysis was conducted on a sub-sample of the data with the help of another researcher who had expertise with respect to pedagogical content knowledge. The sub-sample contained data from three teachers, or 50% of the data. Reliability was at the level of agreement on judgments of the categories that matched the activities described by the teachers. Inter-rater agreement was 83%, and disagreements were settled by mutual consent.

Use of strategies. With respect to the use of strategies in their teaching about heat energy and temperature, the teachers mainly used curriculum materials developed during UMMPP summer workshops. A list of those activities as well as activities included in the teachers' district curricula was compiled (see Appendix A), and each teacher was asked to indicate which activities he or she utilized as a part of his or her instruction in heat energy and temperature. Using the same criteria detailed previously, the activities on this list were categorized on the basis of how the content was represented and whether they emphasized the distinction between heat energy and temperature. Judgment of which activities emphasized the distinction was performed by the first author of this paper and the co-principal investigators of the UMMPP. Inter-rater agreement was 100%.

Results and Significance

Knowledge of Strategies

Table 2 shows the teachers' knowledge of strategies for distinguishing between heat energy and temperature. The number of different strategies described by the teachers ranged from two to six, with an average of four. The number of strategies they described that contained situations emphasizing the distinction between heat energy and temperature ranged from one to four with an average of just over two. Teachers who described activities emphasizing the distinction between heat energy and temperature exhibit knowledge of powerful representations for helping students understand a critical idea for this topic area: the distinction between heat energy and temperature.

Most of the knowledge exhibited by the teachers was about laboratory activities, due largely to the language of the interview questions. Before discussing the results for the teachers, notice that in three of the categories there is information that activities fitting the category typically require use of the heat pulser peripheral, and that those categories are ones which emphasize the distinction between heat energy and temperature. Those activities would be difficult or impossible to conduct without the pulser, or the use of the pulser make the activities more powerful because it permits the control and quantification of the amount of energy transfer. Thus, the very fact that several of the categories with the desired representation of the content are possible activities because of the heat pulser illustrates that it is an important tool for conducting activities that powerfully represent the content. This conclusion supports the contentions of others that microcomputer-based laboratories provide powerful learning opportunities for students (e.g., Nachmias & Linn, 1987). Furthermore, with knowledge that the distinction between heat energy and temperature as important for powerful representation of this content, teachers could develop additional activities using the heat pulser peripheral, and build a stronger base of activities with the desired representation of the content.

Turning to the results exhibiting the teachers' knowledge of instruction with respect to the representation of the content, Table 2 shows that the categories of laboratory activities matched by the most teachers were 1, 2, and 3. These categories all involved volume as the independent variable (see Figure 1), but they had different dependent and controlled variables. All of the teachers exhibited slightly different knowledge in the spring interview, but the total number of categories of laboratory activities matched by each teacher was about the same or more in both interviews, if we consider a difference of one in the totals to be a non-meaningful difference. Ms. Carlson's fall interview results were unique in that they provided the only instance in which all the laboratory activities described by a teacher were classified in categories that emphasized the distinction between heat energy and temperature.

The totals in the table show some interesting patterns. First, the total number of strategies described by each teacher often differed substantially from the total number of strategies described that emphasized the distinction between heat energy and temperature. Part of the difference was due to the fact that the information provided by teachers about "textbook readings" and "discussion" categories could not be evaluated in terms of whether they emphasized the distinction between heat energy and temperature; hence, they could not be included in the tabulation of the number of strategies which emphasized the distinction. Nevertheless, the results also indicate that the teachers could have stronger pedagogical content knowledge. For example, Ms. Carlson and Ms. Lowry both described a large number of strategies, but Ms. Carlson had a larger proportion of those strategies which matched the categories that emphasized the distinction between heat energy and temperature. Thus, Ms. Carlson arguably exhibited stronger pedagogical content knowledge than Ms. Lowry.

Second, if a difference of one is probably not meaningful[4], all of the teachers exhibited about the same or more desired pedagogical content knowledge (i.e., good representations, those that emphasized the distinction between heat energy and temperature) in the spring interview. If that relationship is valid, it suggests evidence of the growth of pedagogical content knowledge as a function of instruction for those teachers who exhibited more knowledge in the spring. This claim is speculative at best from these data, but the idea warrants further investigation.

Third, despite the growth that these results may demonstrate, what they reveal in general is that most of the teachers did *not* exhibit substantial knowledge of activities emphasizing the distinction between heat energy and temperature, despite the fact that the interview questions explicitly or implicitly requested that they describe what they would do to help students understand that distinction. One explanation for this result is that the teachers' knowledge was impoverished in this respect; that they did not know which laboratory activities contained the most powerful representations. Another explanation is that the teachers' framework for organizing their knowledge was differentiated with respect to how the content was represented in an activity. Instead, it was organized by more surface features, i.e., whether an activity dealt with temperature or heat energy, and whether it included particular elements regarding heat energy transfer (e.g., volume). Because the distinction between heat energy and temperature is a critical feature of this subject matter, a lack of organization with respect to that attribute would be evidence of under–developed or under–differentiated knowledge for these teachers, despite their experience and expertise. This result illustrates that even well-respected and knowledgeable teachers may not have the expert knowledge for teaching specific subject matter that we can now readily identify using the concept of pedagogical content knowledge and the issue of representation. Given that result, it is clear that more research examining teacher knowledge about instruction is needed, especially from this perspective of the distinguishing instructional activities on the basis of the representation of the content.

Use of Strategies

Table 3 shows the categorization of laboratory activities conducted by each teacher. The results indicate that although the teachers were very similar (with one exception) in the total number of activities they conducted, there was substantial variation in the number of activities they conducted which emphasized the distinction between heat energy and temperature. Furthermore, there was no clear pattern between the kinds of activities emphasizing the distinction between heat energy and temperature that they described in the *interview*, and the kinds of activities emphasizing the distinction between heat energy and temperature that they conducted during their *instruction*. Thus, there was not a one-to-one correspondence between the teachers' knowledge and their use of instructional tasks with the most powerful representations of the subject matter.

We can explain this discrepancy for one of the teachers, Mr. Roberts. Mr. Roberts did not conduct any activities emphasizing the distinction between heat energy and temperature, despite the fact that he knew of activities that would be appropriate to conduct (see Table 2). What his spring interview revealed, however, was that his instruction that year focused on temperature, not heat energy, and he did not formally address the concept of heat energy with his students. Given that information, it makes sense that none of his instructional activities emphasized the distinction between heat energy and temperature. From that we can also reason that the lack of specificity in Mr. Roberts' description of activities for helping students understand about the distinction between heat energy and temperature (see "Other" category in Table 2) was related to the fact that he did not conduct any instruction dealing with the distinction. Because Mr. Roberts wasn't teaching about heat energy, he didn't consider the issue of the relationship between heat energy and temperature outside of the interview context when he was formally asked about it. Thus, he didn't plan or have any experiences that would have allowed him to recall relevant activities in the spring interview.

Although we can reasonably explain the discrepancy in the data in Mr. Roberts case, this study was not designed to capture information that would allow us to search for an explanation of the discrepancy between knowledge and use of strategies for other teachers. Of particular interest are the results for two of the teachers, Ms. Carlson and Ms. Lowry. Both of these teachers taught in the same school district at the same grade level, and, presumably, carried out the same curriculum. Both teachers exhibited similarly strong desired pedagogical content knowledge in the spring interview (i.e., strategies emphasizing the distinction between heat energy and temperature) and yet they differed substantially in the type and number of instructional activities they conducted that emphasized the distinction between heat energy and temperature. How and why did they arrive at such decisions? Because Ms. Carlson exhibited the most differentiated desired pedagogical content knowledge in both interviews (i.e., she exhibited knowledge in the most categories) we might have expected her to use the greatest number of strategies emphasizing the distinction, but she did not, Ms. Lowry did. Is this a case of Ms. Carlson having the knowledge and not using it? Or, did Ms. Lowry and Ms. Carlson simply have different instructional goals, despite teaching the same curriculum? The answers to these questions are beyond the scope of the study, but they point to the need for investigations examining teacher thinking in relation to specific content goals of specific instruction. We need to find out more about how teachers think particular instructional activities will help students' develop understanding, and we need to examine that thinking against the type of conceptual analysis of the instruction carried out in this study.

Summary

In sum, the conceptual analysis undertaken in this study demonstrates the utility of a conceptual analysis of instructional activities with respect to representation of content. Such an analysis allows comparison of instructional activities that may be very different contextually, and it may provide a framework for conceiving new activities that are powerful representations of the content. The results in this study also suggested a pattern in teacher knowledge about instruction for this content that is of concern: the teachers did not appear to have differentiated knowledge of instructional tasks with respect to the distinction between heat energy and temperature, an important feature of powerful representations in this topic area.

This finding and has implications for teacher preparation (pre-service as well as in-service) in this as well as other topic areas. If, as Caramazza, McCloskey, and Green (1981) have suggested, "the historical persistence of [alternative] beliefs suggests that they are a natural outcome of experience with the world" (p. 122), such knowledge is important to account for in representations of content, and should be considered in the determination of useful instructional activities for fostering the development of scientific knowledge. Teachers need to carefully evaluate instructional activities with respect to what they conceptually emphasize, from the perspective of what conceptual issues the learners are likely to find difficulty with. In the case of the content examined in this study, for example, it is not sufficient to have students compare cooling curves for different volumes of water and compare the time of cooling, assuming they will conclude that the volume that took longer to cool lost more heat energy. This is not a direct comparison of heat energy and temperature. In contrast, if they use the heat pulser, they can determine that it takes more pulses to change the temperature of a larger volume of water the same amount as a smaller volume. If we conduct instruction bearing this perspective in mind, we may find that naive conceptions are not as problematic as they have typically been portrayed (Champagne, Gunstone, & Klopfer, 1983; Eaton, Anderson, & Smith, 1984; Nussbaum & Novick, 1982; Osborne & Freyberg, 1985), and that the use of powerful instructional strategies will be very effective in addressing the issue of the naive conceptions students bring to instruction.

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] Interview protocols are from the UMMPP (Krajcik & Layman, 1987), and exact protocols can be found in Magnusson (1991).
[3] It should not be assumed that by not indicating an amount for a category that we think that is insignificant information. It may be that being able to describe several activities fitting the same category is indicative of a "richer" knowledge base. That determination, however, was beyond the scope of this study.
4 Assuming interviewer effects could account for a difference of one but not two.

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CATEGORY	VARIABLES			DESCRIPTION	
	Independent	Dependent	Controlled	Generic Description	Example Activity
1. a.	volume	time	T/ΔHE	a. Different volumes at the same T; add same amount of ice & compare time for ice to melt.	a. Add 20 grams of ice to 50mL and 100mL of room temperature water and compare time for ice to melt.
b.			ΔT	b. Different volumes with the same ΔT; compare the amount time for ΔT, infer amount of HE transferred.	b. Let 50mL & 100mL of water at 50°C cool to room temperature. Compare the time each takes to cool; conclude about heat energy lost.
2. a.	*volume*	*ΔHE*	*temperature*	*a. Different volumes at the same T; compare amount HE required to maintain T.*	*a. Use the heat pulser to keep 50mL & 100mL of water at 50°C, compare number of pulses to maintain T.*
b.			*ΔT*	*b. Different volumes with the same ΔT; compare am nt of HE transferred.*	*b. Let 50ml & 100mL of water at 50°C cool to room temperature. Calculate amount of heat energy transferred.*
3. a	*volume*	*ΔT*	*temperature*	*a. Different volumes at the same T; compare ΔT_{mix} after adding each to same volume.*	*a. Add 25mL and 50mL of water at 25°C each to 25 mL of 0°C water and compare ΔT that results.*
b			*ΔHE*	*b. Different volumes w/ same amount of HE added; compare ΔT.*	*b. Using the heat pulser, add the same number of pulses to 25mL and 50mL of water at 25°C and compare the ΔT for each.*
4.	*material*	*ΔT*	*ΔHE*	*Different substances with same amount of HE added; compare ΔT.*	*Using the heat pulser, add the same number of pulses to 50mL each of water & alcohol, and compare the ΔT for each.*
5. a.		ΔT	ΔHE/vol.	Transfer of heat energy via conduction.	a. Place 100mL of hot and cold water in styrofoam containers connected by a conduction bar. Record the temperature change in each cup over time.
b		time	ΔHE/vol.		b. Plot cooling vcurve as substance cools.
6	HE added	ΔT	volume	Same volume with different amounts of HE added; compare ΔT.	Using the heat pulser, add varying numbers of heat pulses to 100mL of water; compare ΔT.
7	*phase change*	*no ΔT*	*ΔHE*	*Melting/freezing point or boiling point*	*Record temperature change from frozen ice to boiling water; compare ΔT during the phase change.*
8.	ΔHE	phase change	ΔT	Change in temperature for substance A as evidence of energy required to change phase of substance B	Cover a thermometer with wet cotton and record the temperature difference after the cotton dries.
9.	*ΔHE*	*ΔT*	*material*	*Calculation of ΔHE from mass, specific heat & ΔT.*	*Burn a peanut below a container of water; measure the ΔT and Δm for the peanut; calculate the amount of HE transferred to the water.*

Figure 1. Categories for examining the representation of concepts in typical laboratory activities about heat energy and temperature. Italicized categories include elements that emphasize the distinction between heat energy and temperature.

Table 1

Characteristics of the Teachers and the Context of Their Heat Energy and Temperature Instruction

Characteristics	TEACHERS Baxter	Carlson	Gentry	Lowry	Mason	Roberts
Years of teaching experience	18	7	24	8	21	13
Years teaching current curriculum	12	5	11	6	10	5
Subject matter taught	earth sci.	physical sci.	physical sci.	physical sci.	physical sci.	earth sci.
Years using MBL in teaching	2	2	2	2	2	2
No. of classes using MBL[a]	4 (4)	4 (4)	3 (3)	4 (4)	5 (5)	4 (4)
Context for using MBL	classroom[b]	classroom	classroom	computer room	classroom	classroom
Number of computers available to students	10	8	8	8	8	11

[a] The number in parentheses is the total number of classes taught by the teacher.

[b] This designation indicates computers were brought into the teacher's classroom whenever MBL activities were performed.

Table 2

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

STRATEGIES	Baxter F	Baxter S	Carlson F	Carlson S	Gentry F	Gentry S	Lowry F	Lowry S	Mason F	Mason S	Roberts F	Roberts S
Textbook Readings			√	√					√	√		
Discussion	√				√	√	√					
Laboratory Activities 1. Ice melting in diff. vol.: time. Diff. vol. cooling: time.	√			√	√	√	√		√			
2. Different vol. at same T: determine amt. HE to maintain T.[a]		*				*						
Different vol. with the same ΔT: compare HE transferred.			*	*	*			*		*		
3. Different vol. at the same T: compare ΔT_{mix} with another vol.			*	*			N/A	N/A				
Different vol. w/ same amount of HE added: compare ΔT.[a]		*	*		*		*	*				
4. Different substances w/ same amount HE added: compare ΔT.[a]			*						*	*		
5. Transfer of heat energy via conduction.												
6. Same vol. w/different amounts of HE added; compare ΔT.		√					√	√				
7. Melting or boiling point.				*				*				
8. ΔT for substance A shows ΔHE for phase change in substance B.												
9. Calculation of ΔHE from mass, specific heat, and ΔT.	*	*									*	*
Other			1				1[b]		1		uns.*	uns.*
TOTAL number of strategies.	3	4	6	5	4	3	6	5	4	3	≥2	≥2
TOTAL emphasizing the distinction between HE & T.	1	3	4	3	2	1	1	3	1	2	≥2	≥2

Key:

*	Activity matched strategy; strategy emphasized the distinction between HE and T.	ΔT	Change in T.
√	Activity matched strategy.	ΔHE	Change in HE.
N/A	Not applicable. Activity described by the teacher used an incorrect variable for comparison.	diff.	Difference.
uns.	Unspecified. Number and type of activities could not be determined but several were implied.	HE	Heat energy.
		T	Temperature.
		vol.	Volume.
		w /	With.

[a] An activity fitting this category typically requires the heat pulser peripheral.

[b] Not enough information to determine whether the distinction between heat energy and temperature was emphasized.

Table 3

Teachers' Heat Energy and Temperature Activities Classified by Representation Category

CATEGORIES	TEACHERS					
	Baxter	Carlson	Gentry	Lowry	Mason	Roberts
1. Diff. vol., compare time for ΔHE.		1*				
2. Diff. vol., compare amount of ΔHE.			1*	1*		
3. Diff. vol., compare ΔT given ΔHE.			1*	1*		
4. Diff. materials, compare ΔT for same ΔHE.[a]	3	1		1	1*[b]	1
5. ΔHE via conduction.	6	2	1		2	4
6. Diff. ΔHE, compare ΔT.	1	1	1	1	1	
7. Melting/boiling point.		1*	1*	1*	1*	
8. ΔT for A shows ΔHE for phase change in B.	1					
9. Calculation of ΔHE.	1*		1*	2*	1*	
Other	5 (1*)	2 (1*)	1	1	1	2
TOTAL	17	8	7	8	7	7
TOTAL emphasizing distinction between HE & T	**2**	**3**	**4**	**5**	**2/3**	**0**

Key:

#	Number of activities that matched strategy.	ΔT	Change in T.
#*	Activity matched strategy; strategy emphasized the distinction between HE and T.	ΔHE	Change in HE.
		diff.	Difference.
		HE	Heat energy.
(#*)	Number of activities out of total that emphasized the distinction between HE and T.	T	Temperature.
		vol.	Volume.

[a] Activities in this category do not necessarily emphasize the distinction between heat energy and temperature if the transfer of energy for each material is not equal.

[b] Activity was used with gifted & talented class only.