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Paper Title: The Influence of Microcomputer-Based Labs on Childrens' Conceptions of Temperature and Temperature Change

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The Influence of Microcomputer-Based Labs on Childrens' Conceptions of Temperature and Temperature Change

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INTRODUCTION

There is a great deal of interest today in constructivism as a theoretical rationale for research and teaching (Lorsbach & Tobin, 1992). Constructivism is a view of knowledge and learning that holds that a learner's existing conceptual framework, sometimes referred to as prior knowledge, dramatically influences the learner's efforts at constructing new knowledge from sensory input. Osborne & Freyberg (1985) capture this notion with the following statement: "Children naturally attempt to make sense of the world in which they live in terms of their experiences, their current knowledge and their use of language (p. 13)." Hence a great deal of recent research has dealt with childrens' existing conceptions (Confrey, 1990).

The focus of much of this research has been on childrens' conceptions which are not in agreement with the experts and have therefore been termed misconceptions or alternative conceptions. Osborne & Freyberg (1985) have termed childrens' alternative conceptions of the natural world as "childrens' science" and report examples of research about conceptions in the areas of mechanics, the particulate nature of matter, electric current, heat and temperature, living things, and earth science to name just a few. They claim: "It is the similarities and differences between childrens' science and scientists' science that are of central importance in the teaching and learning of science. One of the underlying assumptions of this study was that a better understanding of the development and substance of children's conceptions can lead to improved teaching, better curricular material, and more fruitful educational research.

Although much of the literature deals with childrens' alternative conceptions, it should not be overlooked that children can hold sound conceptions about many aspects of the world. Perhaps it is most useful to think in terms of a child holding a range of conceptions in a large number of domains; these conceptions ranging from sound (as defined by consensus of experts) to highly inaccurate (alternative). Careful investigation of the range of conceptions a learner holds is a valuable goal.

Those domains of science mentioned above deal with fundamental quantities which every child experiences almost daily. In part because of this everyday contact children begin to intuitively construct conceptions about these and related quantities from an early age. Such conceptions are formed early, usually before formal instruction, and intuitively, that is using existing conceptions and logic schemes, and, as a result are often firmly held and difficult to influence or change. Thermodynamics is one such domain where children have numerous opportunities to construct conceptions intuitively. Heat and temperature are fundamental to much of physical science (Linn & Songer, 1988) and as one of the subjects in the current study described temperature: "It's a big part of life"(B1.100). Consequently, childrens' conceptions about heat and temperature are significant and worthy of close investigation.

There are a number of hurdles a learner has to overcome in constructing sound conceptions about heat and temperature. The sense of touch is subjective and can be misleading in forming sound conceptions about the correct temperatures of objects; fingers do not make very accurate thermometers. For example, it is a common belief that a metal leg is colder than the wooden part of the same chair. A related hurdle stems from a lack of awareness of the actual temperatures of common materials and objects. Temperature is not a readily apparent property of objects as is shape or color. Without touching an object - and even then the judgment can lack accuracy - we have no means of determining the temperature of an object without a thermometer or other sensing device. Consequently, temperature judgments of objects in a room are left up to inference or prior experience. A third hurdle to sound conceptual development arises from everyday language concerning heat and temperature. We often use the expression "have a temperature" when describing a body temperature elevated above normal. Does this imply that a healthy person does not have any temperature?

One way to overcome the first two hurdles is to utilize an accurate temperature-sensing tool. A thermometer is one such tool historically and typically used to accurately determine temperature. Another tool more recently developed and currently available for use by students is a microcomputer equipped with a temperature probe and appropriate software. Such a tool can measure, record, and display accurate temperature(s) of one or more systems as a real-time graph. Lab investigations utilizing such equipment are usually referred to as microcomputer-based laboratories (MBL). Using a microcomputer in this manner offers a fundamentally new way of supporting students' construction of thermal concepts (Krajcik & Layman, 1989).

PURPOSE AND OVERVIEW

This study was designed to augment the growing research on childrens' conceptions in Science. It was founded on the constructivist model of learning and sought to identify and illuminate student conceptions, both correct and alternative, about particular temperature concepts. Specifically, the purpose of this study was to examine in detail eight fourth-graders' conceptions about temperature and temperature change before and after they experienced temperature measurement microcomputer-based laboratories (TM - MBL). The students had been selected for the study based on evidence obtained from a screening test indicating that they held alternative conceptions about: a) the intensive property of temperature and b) the influence of volume on the time for warming and cooling common liquids. Intensive here is defined as a property that is the same throughout a system, regardless of mass, assuming the system is in thermodynamic equilibrium. Additionally, mass, or volume as the students observed, influences the time it takes for a liquid to warm or cool a given temperature. alternative conceptions related to these two concepts have been documented in the literature (Appleton, 1984; Erickson, 1979).

The TM - MBL student activities involved a series of five progressive labs designed to facilitate change in the students' alternative conceptions about the aforementioned concepts. The students worked on the lab activities in pairs during five separate days. Information about the students' conceptions was gathered before and after TM - MBL using semi-structured interviews which were subsequently transformed into conceptual inventories. Change in student conceptions was examined by comparing conceptual inventories constructed before TM - MBL to inventories constructed after TM - MBL.

METHOD

The choice of thermal concepts on which to base this study was determined by certain criteria: a) the concepts appeared in the alternative conception literature; b) they were conceptually appropriate for upper elementary students; c) they utilized the potential of MBL; d) they related to common thermal experiences of children; and e) they would be worthwhile for students to know. Using these criteria, two temperature-related concepts were selected which had associated alternative conceptions as reported in the literature. These appear as (target) concepts numbers three and six in

Appendix A. The entire set of target concepts was derived after an initial analysis of interview data collected during a pilot study. The target concepts served as a framework to guide the development of a conceptual inventory outline (see Appendix B) and the Scientists' Concept Map of Temperature (see Appendix C). The conceptual inventory outline guided the analysis of the interview transcripts; this analysis resulted in individual conceptual inventories for each student before and after their TM - MBL activities. The conceptual inventories served as the primary method of data transformation for the study and were similar to those developed and used by Erickson (1979). The development and refinement of the concept map aided the author in identifying the significant science concepts of the study and their relationships to each other.

Because the study was designed to look for conceptual change, it was essential that all students chosen for the study initially hold a specific alternative conception, preferably two, elaborated below. A screening test was designed to elicit alternative conceptions about two specific concepts dealing with temperature. One requisite alternative conception was that the temperature of a small sample of water is <u>not</u> the same as the temperature of the water from which the sample was drawn. This concept is counter to that held by scientists, namely the temperature of a small sample of water is the same as the temperature of the larger body of water from which it was drawn. This concept deals with a property of temperature referred to as intensivity and has been documented in the literature as one commonly held by children (Appleton, 1984; Erickson, 1979; Wiser, 1987).

A second requisite alternative conception, and the primary focus of this study, was that the time for heating and cooling of a sample of water does <u>not</u> depend on the volume of water. This alternative conception has been documented by Appleton (1984), Wiser & Kipman (1988), and Lewis & Linn (1989) and is not that held by scientists. The accepted concept is that volume is an important factor in the time it takes to heat or cool water - or any other substance - a given temperature. This is a fundamental concept in thermodynamics and is important in developing a distinction between the fundamental concepts of heat and temperature (Wiser & Carey, 1983). The screening test was administered to the 35 fourth graders in a suburban Washington D.C. public school. Based on the results of the test, eight fourth grade students, four boys and four girls, were selected to participate in the study. A scoring scheme was developed to rate and rank each student based on both these specific alternative conceptions.

Essential to this study was the need to gather information about student conceptions dealing with a specific topic. The literature dealing with student conceptions describes many studies that have used interview techniques as the primary method of collecting this information (Erickson, 1979; Posner & Gertzog, 1982; Stewart, 1980; and Linn et al., 1990). Carefully constructed interviews allow the collection of rich information about specific student conceptions. The interactive nature of an interview allows extensive and dynamic probing of a student's conceptions. After analyzing the interview data from the pilot study, the author concluded that a 45-minute interview was not long enough to allow the collection of sufficient information from the students to be able to make reasonably accurate inferences about their conceptions. In addition, Novak and Gowin (1984) suggested that an interview of about 30 - 40 minutes is about as long as young students can handle. Consequently, both the interview before TM - MBL and the interview after TM - MBL were each divided into two sessions, each lasting approximately 40 minutes. This extra amount of interview time permitted a deeper and richer probing of each student's conceptions than would a single interview. The interviews were conducted by the author at the students' school before the start of classes in the morning. This had the advantage of engaging the students at the beginning of the day when they were less tired.

The interview protocol was derived from the target concepts which had been developed during analysis of the pilot data. The interview presented several tasks to the student which called for temperature judgments of different volumes of water taken from one large container. Additional tasks probed the student's conceptions of the conditions that cause heating and cooling of objects. Problem situations dealing with different volumes of liquids were presented in order to elicit conceptions about the influence of volume on the time for heating and cooling. The last phase of the interview examined the students' graph reading and interpretation skills.

The students' TM - MBL experiences consisted of a familiarization and training session followed by four additional lab sessions during which the students investigated specific temperature phenomena using TM - MBL. The purpose of the training session was to familiarize the students with TM - MBL and the four lab sessions provided the students with opportunities to explore specific temperature phenomena using TM - MBL. Each lab activity lasted about 50 to 60 minutes, was held in a classroom in the students' school before the school day, and was supervised by an adult trained by the author.

The transformation of the interview data began with professional transcription of the interview audiotapes. Construction of an individual student conceptual inventory began when the author listened to the audiotape of the interview and made necessary corrections on the typed transcript. Relevant student propositional statements were then typed into a computer in the conceptual outline mentioned above. The author used an outline software application with the same outline serving as a standard template for all conceptual inventories. When a student's statement was fragmented or otherwise not easy to understand it was paraphrased as it was typed into the outline with an attempt to preserve significant words used by the student. Statements that were alternative and did not agree with the accepted scientific point of view were typed in italics. Each statement typed in the outline was referenced with a number to the original statement in the transcript from which it was taken.

The conceptual inventory was developed to three levels. The first level was a key segment of the target concept, the second level was the subtopic, and the third level was where the student's propositional statements were entered and referenced. Once all the appropriate statements from a transcript were entered into the outline, a summarizing statement was created for each subtopic. This summarizing statement was an interpretation by the author of the conceptions the student exhibited about the particular subtopic. If the conception represented by the summarizing statement was alternative, the statement was typed in italics. If part of the summarizing statement was alternative then only that part that was alternative was typed in italics. The collection of summarizing statements within each target concept served to describe the student's conceptions about that particular concept. The total collection of summarizing statements for all of the target concepts served as the conceptual inventory for the student. An example of a conceptual inventory collapsed to two levels appears in Appendix D. All conceptual inventories followed the structure of the Conceptual Inventory Outline. Inventories constructed for one student matched those for another student and inventories representing conceptions before TM - MBL matched those after TM - MBL. The exception to this rule was where a level had been added at the end of a subconcept to identify a conception that was unique and noteworthy to that particular student.

Once all the individual student conceptual inventories had been constructed, they became a useful tool to view the spectrum of student conceptions. The set of conceptual inventories served as an index to the 500 pages of interview transcripts, permitting easy referencing during the analysis to specific student statements. For each subtopic, the author read through each student's conceptual inventory to identify conceptions that were common to more than one student and conceptions that were unique to only one student. The results of this analysis follow.

RESULTS AND DISCUSSION

In the dissertation from which this paper is derived, part of Chapter 4 was devoted to describing individual student conceptions for each of the eight students as well as describing conceptions that were common to at least two students. This paper will discuss only the more significant common conceptions.

Temperatures of Objects

Some of the more interesting results found in this study deal with the reported temperatures of different objects. Alternative conceptions about the perceived temperatures of ordinary objects were uncovered when students were asked: "Do all objects have temperatures?" and when they were asked to predict final temperatures of beverages in warming and cooling situations. The results suggest that: a) for some students, not all objects have a temperature; b)students often judged temperatures different from what a scientist would report: and c)air played a significant role for some students in influencing temperature and temperature change. Each of these items will be discussed below.

Not all objects have a temperature.

One of the more significant findings of the study was the alternative conception exhibited before TM - MBL by five of the eight students that not all objects would have a temperature. The objects that students mentioned as not having a temperature included the table at which the interview was conducted, a taperecorder, paper, a BandAid, a wall, a chair, a plastic tab, and underwater. Several of the reasons offered for this alternative conception can be traced to sensorial experiences and language, two of three suggested influences on the formation of student's conceptions reviewed by Driver and Erickson (1983).

On several occasions during the interviews, students felt the table with their hand before reporting that it did not have a temperature. Since the table was at room temperature and not a particularly good conductor of heat, it seems likely that the surface of the table did not feel either warm or cool to the students. Temperature detection using the sense of touch depends heavily on sensations caused by the transfer of heat either into or away from the skin. Contact with an object of the same temperature as the skin produces no noticeable sensation and consequently the object could be perceived as lacking a temperature. For these students, 'having a temperature' would have to feel either warm (or hot) or cool (cold). Therefore, objects that have the same temperature as the skin might be perceived as having 'no temperature'. (Heat conductivity is at the root of a related common alternative conception found in this and other studies (Lewis & Linn, 1989), namely that metal feels colder than other materials which are at the same temperature.) One further statement supporting this argument came from Joan. She suggested that a piece of paper would not have a temperature because it was thin and therefore wouldn't get very cold or hot. Bonnie had also expressed the same conception but offered no supporting reason.

Another possible source of this alternative conception might be found in our language. A definition commonly given for 'temperature' is: "how hot or how cold something is." This definition leaves out the concept of an in-between or intermediate temperature. Strict adherence to this definition implies that to have a temperature, an object has to be either hot or cold in varying amounts. In fact, this two-fold definition was used by five of the eight students in the study. If temperature is thought of in terms of only hot and/or cold, then intermediate temperatures would not be part of this concept of temperature. Three students did include an intermediate state, medium. A second linguistic-based reason for the development of this particular alternative conception might be found in the phrase: " . . . have a temperature" used commonly in reference to a body temperature elevated above normal. When body temperature is normal, one is said not to have a temperature. A logical inference from this would support the conception that human bodies and other objects could have 'no temperature'.

Another reason offered by one student, Tony, to explain why some objects don't have a temperature is a lack of contact with air. Tony felt that if objects like paper and pencils did not contain air, they would not have a temperature. According to Tony, if a little amount of air got in or was in these objects, then they would have a little amount of temperature. Tony applied this alternative conception to the temperature of water in a glass, even after TM - MBL. He claimed that below the surface of the water, since there was no air, there would be no temperature also. A prime example of this alternative conception was Tony's description of a bank safe-deposit box. According to Tony, the metal the box was made of would not allow any air to enter, and so there would be no air - and consequently no temperature - inside. This alternative conception relates to other conceptions Tony expressed elsewhere in his interview that heat is a substance and that temperature and heat are the same thing .

The reasons discussed above for the alternative conception that not all objects have a temperature are either sensorial or language based, or, in Tony's case, relate to a mechanism for how an object acquires its temperature in the first place. The fact that this alternative conception was observed at all in the study indicates that these particular students' lacked a complete and correct conception of temperature.

The TM - MBL activities appeared to have strengthened student conceptions of temperature as a property of all objects. After TM - MBL there were only two students - as compared to five before TM - MBL - who said some objects would not have a temperature, one who said probably all objects have a temperature, and five who said yes, all objects have a temperature. In all likelihood, the experiences the students had measuring temperatures with both a thermometer and a temperature probe and working with the resulting graphs strengthened their overall conceptions of temperature. A stronger conception of temperature now included intermediate as well as cold and warm temperatures. Exemplifying this change in conception was a comment from Richard. Before TM - MBL, he firmly exhibited the conception that the table did not have a temperature. After TM - MBL, when asked if the table had a temperature, he responded: "Yeah, you'd have to stick a probe or thermometer - drill a hole in it and put it in" (R2.289). It is not clear from this study how much if any of this improved conception was due to the TM - MBL component of the lab activities and how much was the result of the students investigating thermal phenomena in a quantitative manner.

<u>Temperature judgments</u>.

This section complements the previous one in that it discusses students' judgments of temperatures of objects, but now for non-zero values. Opportunities to elicit such temperature judgments occurred throughout the interview. Many came during that part of the interview that probed the student's predictions of final temperatures during the thermal equilibrium and intensivity tasks. Additional temperature judgments were offered at other points during the interview when the student was asked about the temperatures of various objects around the room. The term 'equilibrium' was not used with the students during the interviews even though some of the tasks and questions intentionally dealt with thermal equilibrium.

Even though all eight students correctly indicated, both before and after TM - MBL, that the temperature of an object's surroundings influenced the final temperature of the object, most did not exhibit strong conceptions about thermal equilibrium. (Appleton [1984] also found that his subjects had a good understanding of the influence of the temperature of the surroundings on changing the temperature of an object.) Before TM - MBL none of the students consistently suggested that the final temperature of an object would be that of its surroundings. A variety of final temperatures were reported along with a variety of reasons to account for those temperature judgments. Some students reported final temperatures to be higher than equilibrium, while others reported temperatures lower than equilibrium. These findings support those reported by Tiberghien (cited in Driver et al.,1985) who suggested: "Pupils, however, have difficulties in recognizing the equality of temperatures at thermal equilibrium" (p. 71).

Some of the reasons that were offered for non-equilibruim temperature judgments appear to fall into two categories: sensorial based and analogical reasoning, both of which Driver and Erickson (1983) summarize from other authors as possible origins of conceptions. A third reason, language, was mentioned earlier. An example of a conception that might have stemmed from sensory experience would be Maria's reports that all drinks are warmer than their surroundings because she once had a juice drink that tasted warm after it had been left in a warm car. Other sensory-based reasons were offered from some of students who reported that a cart would be colder than other objects in the room because it was made of metal. Some of the students also reported that water would be colder because it felt colder than other objects in the room.

A conception that might have stemmed from analogical reasoning was Andrew's report that he'd read and studied that the center of the sun was warmer than the outside of the sun. By analogy the potato used in the interview would therefore be much warmer after a long period of time than the oven it was in because the potato was in the center of the oven. He used this comparison with the sun several times to explain temperature judgments. Another example of analogical reasoning came from Joan who suggested that the water in a large black tub would be warmer than the water in the smaller white pitcher because, she said, black generates heat. Tony, on the other hand, reported just the opposite conception: the temperature of the water in the large black tub would be cooler than that in the smaller white pitcher because of his reported experience with cold water in a large swimming pool. These conceptions appear to be based on analogical reasoning also. Other reasons offered for non-equilibrium final temperature judgments were so idiosyncratic as to not easily fit into these or other categories. Indeed, one of the essential features of conceptions is that they are so idiosyncratic because of the unique conceptual framework of each individual.

Another influence on correct temperature judgments should be noted here. In addition to incorrect temperature judgments from four of the eight students before TM - MBL on the intensivity task (temperatures of various amounts of water from the same source), there were two other occasions when students offered lower-than-expected temperature judgments of a substance, namely paper. When asked if anything in the room would be less than 70 degrees, Joan replied: ". . . I said the paper maybe because well it is thin . . . and um it would be smaller so . . . it would probably [not be] as hot as 70 degrees. Maybe it would be around 60 degrees" (J1.307). When asked then if thin things tend to be cooler, she replied: "Yeah." Another student, Bonnie, exhibited a similar alternative conception at the same point in the interview. Bonnie was reporting temperatures of objects, all somewhat lower than the agreed on 70°F room temperature, but when asked about the temperature of paper in the room, she replied: "Ugh!" When asked why she responded this way, her reply was: "Because it's kind of hard. 54 [degrees]" (B2.287-289). Unfortunately, persistent probing by the interviewer did not produce any insight as to why this was a particularly hard judgment for Bonnie to make. What was significant, however, was that both girls offered temperature judgments lower than room temperature for paper.

If these lower-than-expected temperature judgments are related to the apparent thinness of the paper, then perhaps the underlying reason for these judgments is the same as that for judging smaller amounts of water to be cooler than larger amounts of the same water, namely a confusion between the concepts of heat and temperature. The latter conception is concerned with the intensive property of temperature and has been well documented in the literature (Erickson, 1979; Stavy & Berkovitz, 1980; and Wiser, 1987). The correct concept is fundamental to others in thermodynamics.

Although most of the substances dealt with in the interview were liquids, there were enough non-liquid substances discussed with the students to suggest that their conceptions of final temperatures were to some extent influenced by the type of material as well. Generally, liquids seemed to be cooler than solid materials in the same surroundings, although, as with Maria, individual experiences might dictate otherwise. Cloth objects tended to be reported warmer than hard solid objects. These judgments hint at similar findings reported by Tiberghien and Barboux (cited in Driver et al., 1985), namely that children ". . . tend to make judgments about the temperature of an object based more on the nature of the material than on the temperature of the surrounding medium" (p. 60).

These alternative conceptions might stem from a lack of knowledge about correct temperature values of everyday objects in thermal equilibrium situations. As a fundamental property of objects and materials, temperature is not as evident as size, shape, or color, all of which can be sensed at a distance. Generally though, objects have to be touched in order to determine their temperature. If objects had their current temperature always displayed on them, perhaps children would not have as much difficulty judging temperatures in a variety of situations. Another aspect of this problem is determining the correct temperature of objects. Skin and the sense of touch are not objective detectors of temperature and consequently perceptions of temperature are often inaccurate. Metals and other good thermal conductors tend to feel cooler than they actually are, while cloth, Styrofoam, and other good thermal insulators tend not to feel cool. Hence, even adults tend to logically infer that temperatures of objects are different from what they actually are.

One solution to the problem of a lack of knowledge about correct temperatures is use of a thermometer. The following quote from Sir Humphry Davy (Roller, 1950, p.11) is apropos here: "Nothing tends so much to the advancement of knowledge as the application of a new instrument." Indeed, it wasn't until the invention of the thermometer near the beginning of the seventeenth century that Francis Bacon was able to accurately measure temperature and then begin to develop a distinction between heat and temperature (Roller, 1950).

The number of correct temperature judgments offered by the students increased after TM - MBL and there was a decrease in the range of incorrect temperature judgments away from thermal equilibrium. More of the students said the final temperature of an object would be that of its surroundings. Such results indicate that experiences measuring the temperatures of objects improves students' conceptions about correct temperatures in thermal equilibrium situations.

Air and Temperature

For most students in this study, air appeared to be a very real and important substance for establishing and changing temperature. Evidence was found throughout the interviews of conceptions about the role of air in: 1) whether or not an object had a temperature, 2) causing a temperature change, 3) the final temperature of an object, and 4) the time for an object to change a given temperature. Of these four aspects of temperature, air played the greatest role for the students in causing a temperature change. Examples of these four different conceptions about air and temperature follow. Tony felt that where there was substance but no air, there could be no temperature. Richard suggested several times that the liquid in a container would not change temperature unless air could contact it. Bonnie thought that the juice inside a juice box would not reach the temperature of its surroundings unless it were open to the air. Joan implied that two V8 Juice cans of different sizes would warm at the same rate because neither can had been opened to the air. Such examples reflect the conceptual link these students had between air and temperature.

Within the eight students there was a range of awareness of air and its effect on the temperature of objects. On one hand, Karl seemed quite unaware of air as a substance, much less one which had a temperature itself and could influence the temperature of other substances. On the other hand, several students went to great lengths to suggest mechanisms to explain how air would make contact with and change the temperature of other substances. It appears that air played a very significant role for students of this age in causing temperature change and in determining temperature. There is limited mention in the literature of childrens' ideas about air and temperature (Appleton, 1984; Erickson, 1979).

These connections between air and temperature seem more logical when student conceptions about heat are examined. When asked about heat, most of the students directly or indirectly mentioned something about temperature change. This usually appeared in the conceptual inventory in the subsection: 'The effects of heat.' There seemed to be a strong association between heat and changing temperature. Our language promotes this association through phrases such as "Heat the soup on the stove." "Close the door or you'll let the heat out (with the implication that it will then get cooler.)" "Heat for 10 minutes in the microwave (and the food will be cooked and/or warmed.)" The other conception to note here is that for five of the students, heat was seen as a substance; for some of them heat was similar to air or hot air. Those students who exhibited the conception that heat was a substance also exhibited the conception that air was necessary in order for temperature to change. One possible conclusion to draw is that for these students, air was a necessary element for temperature change because heat was a substance in or like air and heat causes temperatures to change. Heat therefore seems to act as some sort of intermediary agent between air and temperature change. The logical conclusion to this argument is that air is necessary for temperature to change.

The strong reliance of temperature on air decreased but did not disappear after TM - MBL. A strong reliance persisted only for Richard. Perhaps the experiences of warming and cooling water samples with water baths allowed the students to develop other conceptions of temperature change that did not depend so heavily on direct contact with air. However, with such limited numbers of students, these results can only hint at the lab activities as the source of these improved conceptions.

The case of Richard's tenacious conceptions about the influence of air in causing temperature change clearly illustrates one of the characteristics of alternative conceptions, namely that they are often firmly held even with evidence provided to the contrary. It was interesting to note to what great lengths Richard would go ("The glass [bottle] has a lot of holes in it that you can't see"[R1.387]) in order to support his alternative conception that air had to make contact with the liquid inside in order for the liquid to change temperature. At one point, Richard was presented with a material (a plastic soda bottle) that he thought did not have holes in it and consequently would not allow air to enter inside to warm the contents. In order to maintain his air-contact mechanism however, he offered the following explanation: "Well, [warm air] could [get in through the plastic] . . but it would be very hard. It usually would go up through here, but I could probably get my fingernail through this small part right there [the cap]" (R1.357). Whatever was necessary, Richard seemed ready to find a way to allow air in to a container in order to facilitate a temperature change. This and similar alternative conceptions support Appleton (1984) who also reported that a significant number of students said that air had to get into a container to cool down or warm up the contents and that air was seen as similar to heat or cold. Erickson (1979) also noted a frequent association of 'heat' or 'cold' with air and commented: "With some of the younger children [aged 6 - 10 years] heat and air were often used interchangeably, whereas the 12-year-olds would distinguish between them but still see them as acting in conjunction with one another" (p. 227). Findings from the current study would seem to support this.

Intensive Property of Temperature

One of the alternative conceptions examined in this study was that a small amount of substance would have a different temperature than the larger amount from which it was taken. This conception deals with the intensive property of temperature and has been reported in the literature (Erickson, 1979; Stavy & Berkovitz, 1980). Exhibiting this particular conception indicates a confusion between the concepts of heat and temperature. The implications of this confusion lead to the assumption that small amounts of a substance are cooler than larger amounts. The argument goes something like this. Large objects are assumed to have more of 'something' than comparable but smaller objects: a large rock is heavier than a small rock, a large bottle of soda lasts longer than a small bottle because it contains more soda, and a large box of popcorn has more popcorn than a small box. If one assumes that a small quantity of material has less heat energy to give up than a larger quantity of that same material and that temperature is the same thing as heat, then it follows that the smaller quantity would have a smaller temperature; that is, it would be cooler. The inverse is true for larger objects: the larger the quantity, the larger the temperature - namely it would be warmer.

There were two questions on the screening test that probed the students' conceptions about the intensive property of temperature. Because it was not the primary focus of the study, only four of the eight students selected for the study held an alternative or inconsistent conception about this property; the other four held the correct conception. One of the lab activities was specifically designed to counter this alternative conception. After TM - MBL, all eight students exhibited the correct conception about the intensive property of temperature. Perhaps the brief experience the students had measuring the temperatures of various quantities of water with the temperature probe was sufficient to correct their alternative conception about this topic.

It is noteworthy that this study found, as did Appleton (1984), that some students will report a lower temperature for a smaller quantity of material while some will report a higher temperature for a smaller quantity of material. One implication of these contrasting reports is that it is important to probe a student's reasons behind a judgment. One of these judgments would indicate a confusion between heat and temperature (a smaller amount is cooler) whereas the other judgment might not indicate such a confusion.

Influence of Volume on the Time for Temperature Change

The amount of heat energy gained or lost by an object is related to the type of substance (specific heat), difference between initial and final temperature, and the mass of the substance; mass in this case is assumed to be proportional to volume. For a given substance, the larger the mass, the longer it takes a constant heat energy input to raise (or output to lower) the temperature by a given amount. The time it takes for a given temperature change to occur is one aspect of the distinction between heat and temperature and was one of the central science concepts underlying this study.

Most of the research dealing with students' abilities to distinguish between heat and temperature has been done at the middle school level (Linn & Songer, 1988; Wiser & Kipman; Krajcik & Layman, 1989). Of the research dealing with younger childrens' (ages 8 to 11) conceptions of heat and temperature, only Appleton (1984) made reference to childrens' inability to distinguish between heat and temperature. His finding emerged most noticeably from a task involving cooling of different quantities of water and the melting time and temperatures of different-sized ice cubes. Appleton's work served as one of the starting points for the current study. Because of this scarcity of research on younger childrens' conceptions of heat and temperature, the current study was unique in looking at 9-year-olds and their conceptions of the distinction between heat and temperature.

Before TM - MBL, only two students, Joan and Andrew, exhibited the correct conception that volume influenced the time it took to warm or cool a liquid a given amount. When the other students exhibited an alternative conception about this phenomena (i.e. volume did not influence the warming or cooling time), they were asked for their reason. The following reasons were given before TM - MBL by more than one student: the initial (and final in one case) temperature of both volumes was the same, different types of substance were involved, and both volumes of liquids were contacting air. One student, Karl, suggested that the presence of the label on the soda bottle might affect the warming and cooling time of a bottle of soda.

Three students noted that the two different quantities of liquid would warm to the same temperature in the same amount of time because both had started out at the same temperature; one student made reference to the common final temperature. By making judgments about the time for warming or cooling based solely on the starting and/or ending temperatures, these students are demonstrating a lack of awareness of the additional influence of volume on warming and cooling times. This focus on initial and final temperature and not volume is indicative of a lack of distinction between heat and temperature on the part of these students.

In addition, it was suggested by three students that the type of substance an object was made of would influence the time for warming or cooling. This is an appropriate factor to consider, but not to the exclusion of the effect of volume. Actually, it was fairly insightful for these students to suggest that the type of material might be a factor in the time for warming or cooling as this relates to the specific heat, or thermal capacity, of the substance and is indeed one of the factors to consider in establishing the time required for a given temperature change.

Contact with air was mentioned by four students as another factor when they were asked their reasons for judging similar cooling and warming times for different volumes. Although air can influence warming and cooling times of a substance through convection, it was not likely that these students were considering this process. As discussed earlier, these students most likely associated heat with changing temperature, heat with air, and therefore associated a change of temperature with air.

It was disappointing that there wasn't more of an improvement after TM - MBL in overall conceptions about the influence of volume on the time required for a given temperature change. After TM - MBL, only four of the eight students consistently expressed correct conceptions dealing with this topic. Most of the reasons the students had offered before TM - MBL for different warming and cooling times were not offered after TM - MBL. Now however, volume was a factor mentioned by four of the students. Two other students exhibited some awareness of the influence of volume but it was either inconsistent or mentioned only after the interviewer brought forth the graphs the students had made during their labs. Half the students exhibited conceptual change about this phenomena.

Conceptions about Heat

Even though students' conceptions of temperature and temperature change were the main focus of this study, their conceptions of heat were of interest also. The students in the study were neither clear nor consistent in expressing their conceptions about heat, leading one to infer that conceptions about heat were not well established in these students. Although all of the lab activities involved heat energy, heat was not specifically brought up in any of the lab directions or recording sheets the students used during the labs.

The majority of students in the study felt that heat was a type of physical substance. In some cases, heat was believed to be the same as hot air. For other students, heat was believed to be related to, but distinct from air. In either case, the substance heat traveled along with air and therefore traveled into and out of systems causing temperatures to change. These findings support those reported in the work of Appleton (1984), Erickson (1979, 1980), and Shayer & Wylam (1981). Heat as a substance would appear to make a very abstract concept, heat, less abstract and consequently more familiar to the student. Equating heat with air further makes the concept more accessible and useful. The conception that heat is a substance can be traced back to an earlier period (sixteenth and seventeenth centuries) of scientific interest in heat and temperature. One student, Richard, epitomized the substance nature of heat by suggesting that temperature was comprised of heat molecules and cold molecules.

One of the more common conceptions dealing with heat concerned the effects of heat. All the students had something to say about what would happen to an object or system if heat was involved. Often this had something to do with a change of temperature; sometimes it related to the effects of cooking. Shayer & Wylam (1981) similarly found that students at this age often associate heat with its effects. Thermal phenomena are so familiar to students of all ages that it is not surprising that students resort to examples of the effects of heat when asked to describe the abstract concept of heat itself.

Generally, temperature was seen as the broader concept by most students, being composed of heat (sometimes mentioned as hot instead), cold, and in some cases, medium. For some of these students, cold was seen as a substance too, one which would lower the temperature of a system rather than raise its temperature. When asked if heat and temperature were the same, most of the students replied yes. Other conceptions expressed by these students indicated they held and applied this conception in other thermal contexts also.

CONCLUSIONS AND IMPLICATIONS

__This paper has presented childrens' conceptions about temperature, temperature change, and heat. Specifically, it reported findings of a study to examine conceptual change of selected 9-year-olds after they experienced a series of microcomputer-based labs designed to counter two specific alternative conceptions about temperature. These alternative conceptions dealt with the intensive property of temperature and the influence of volume on the time required for liquids to change a given temperature. In addition, the study revealed several alternative conceptions about temperature dealing with objects not having a temperature at all and with the important role of air in determining temperature and effecting temperature change.

Insights into childrens' thinking were revealed when the students offered their reasons for temperature judgments of a variety of objects and materials. Childrens' temperature judgments ranged from saying some objects had no temperature to offering temperatures that were either lower or higher than actual temperatures. The reasons offered for various temperature judgments appeared to stem from several underlying methods of constructing conceptions. Evidence was found indicating that some students relied on sensorial impressions, present and past, to help form their conceptions of temperature. Some evidence was found that everyday language can contribute to conceptual formation as well. A few reasons for temperature judgments offered during the interviews appeared to be based on analogical reasoning. These influences on conceptual formation are similar to those reviewed by Driver and Erickson (1983).

The students' reasons for their temperature judgments also offers some insight into their confusion between the concepts of temperature and heat. This is a difficult distinction to make but one that is important to a sound understanding of these two concepts. In this study, lower-than-expected temperature judgments due to the small quantity of material under question suggest the possibility the students were equating temperature with heat. Evidence of the other alternative conception looked at in this study, the influence of volume on the time for warming and cooling, also suggests a possible confusion between these two concepts.

The TM - MBL experiences did bring about positive conceptual change in some of the students. Fewer students reported that some objects don't have a temperature; more students exhibited a correct conception about the intensive property of temperature; students more often reported correct temperatures on thermal equilibrium tasks; and the perceived influence of the role of air in causing temperature change, in determining equilibrium temperature, and in determining the time for temperature change was reduced. This study was not able to demonstrate whether these changes might have occurred with comparable, non-MBL lab activities. The changes that were observed however point to a number of subtle but meaningful changes in conceptions about temperature.

Some implications derived from this study can be summarized as follows:

Implications for Practice

1. Sound instruction would provide a broad description of temperature for students that included the concept that all objects have temperatures and that temperature is a property of all objects as are color, size, shape, and mass. Such instruction would include a definition of temperature that included a range of values, not only how hot or how cold an object was. It would provide numerous experiences for students to measure and compare a range of temperatures of different objects, including objects which were at 'normal' or 'regular' or room temperature.
2. To improve conceptions of thermal equilibrium, students would measure the temperatures of common objects and compare them with temperatures of other objects in the same room; this could be done with either a standard thermometer or a temperature probe.
3. Students could further improve conceptions of thermal equilibrium if they utilized TM - MBL to monitor the temperatures of two interacting systems as the temperatures approached each other in warming or cooling situations.
4. Teachers might be better able to identify which students held the alternative conception that heat is a substance, a conception that is not readily apparent, if they were alerted to look for students who insist on including air in their explanations of temperature change.
5. Teachers could better identify which students are not able to distinguish between heat and temperature if they can recognize which students hold alternative conceptions about the intensive property of temperature.

6. A meaningful curriculum would facilitate the development of a broad concept of energy in the students first and then pursue the concept of heat energy in greater detail.
7. Teachers should involve students more in observing systems undergoing temperature changes. If conducted with TM - MBL, these observations would have the potential to foster sound conceptions which could lead to a better distinction between heat and temperature.
8. Use of TM - MBL with its accompanying real-time graphing could benefit students who are just beginning to develop graph reading and interpretation skills.

Generally, if teachers became more aware of and appreciated the alternative conceptions presented in this and similar studies, they would be in a better position to provide an appropriate environment in which active learners could construct sound conceptions about temperature and temperature change.

Implications for Further Research

1. Probing into students' explanations for why objects might not have a temperature could add valuable insight into student conceptions of temperature.
2. Further research might be directed at students' conceptions about the temperature of an object as the mass or size of that object approached zero.
3. Research might inquire whether students think that a temperature of zero degrees is the same as having no temperature.
4. Further research might focus on conceptions about the properties of an object and whether that object has a temperature. Some properties to consider would be mass, color, state of matter, and density.
5. Inquiry could focus on conceptions about temperatures of objects and the sense of touch.
6. It would be fruitful to investigate students' conceptions of thermal equilibrium.
7. Further research might focus on childrens' conceptions of the role of air in determining temperature and temperature change.
8. It would be fruitful to know more about childrens' conceptions of air as a substance, the temperature of air, and the mechanisms for how air influences the temperature of objects it surrounds.
9. Is TM - MBL in graphing mode more effective for students than a standard thermometer in promoting correct conceptions about the intensive property of temperature?

10. Additional research needs to be carried out as to the effectiveness of TM - MBL in improving student conceptions about the influence of volume on the time required for a given temperature change.

Research and practice have shown that children develop their own conceptions about the natural world and that it is important to look closely at these conceptions. The students in this study exhibited a range of conceptions, correct and alternative, about temperature and temperature change. Results from the study contribute to existing research documenting childrens' alternative conceptions about the intensive property of temperature and about the influence of volume on the time for warming or cooling. The evidence found for childrens' conceptions about perceived temperatures of objects, childrens' strong conceptions linking air, heat, and temperature, and childrens' improved conceptions about temperature after TM - MBL provides a basis for continued improvement of educational practice and research.

Appendix A

Target Concepts

1. TEMPERATURE IS A PROPERTY MEASURED BY THERMOMETER
   Temperature is the property of an object that is measured by a thermometer.

2. A THERMOMETER MEASURES TEMPERATURE
   The temperature of an object can be measured by a thermometer.

3. TEMPERATURE IS AN INTENSIVE PROPERTY
   The temperature of a system in thermodynamic equilibrium is the same at all points throughout the system; temperature is independent of the mass of the system.

4. A CHANGE OF TEMPERATURE IS INFLUENCED BY THE TEMPERATURE OF THE SURROUNDINGS
   A change in temperature of an object will occur if it is in thermal contact with surroundings which are at a different temperature.

5. EQUILIBRIUM TEMPERATURE IS A CONSTANT TEMPERATURE
   The temperature of an object will remain constant, in equilibrium, if it is in thermal contact with surroundings that are at the same temperature.

6. THE TIME FOR CHANGE OF TEMPERATURE DEPENDS ON AN OBJECT'S MASS
   The time it takes an object to change a given temperature is directly proportional to the mass of the object.

7. HEAT IS A FORM OF ENERGY
   Heat is that form of energy which is transferred between an object and its surroundings due to a difference in temperature.

Appendix B

<u>Conceptual Inventory Outline</u>

1. **Description of Temperature**
    1.1. Definition
    1.2. Degrees
    1.3. What objects have temperatures?
    1.4. Air and temperature
    1.5. Sense of touch

2. **Thermometers**
    2.1. What thermometers do
    2.2. Thermometer use

3. **Intensive Property of Temperature**
    3.1. Size - temperature connection

4. **Change of Temperature**
    4.1. Temperature change due to surrounding temperature
    4.2. Other factors affecting change of temperature
    4.3. Heating - cooling symmetry
    4.4. Terms used

5. **Equilibrium Temperature**
    5.1. Final temperature
    5.2. Factors preventing equilibrium
    5.3. Role of air
    5.4. Room temperature

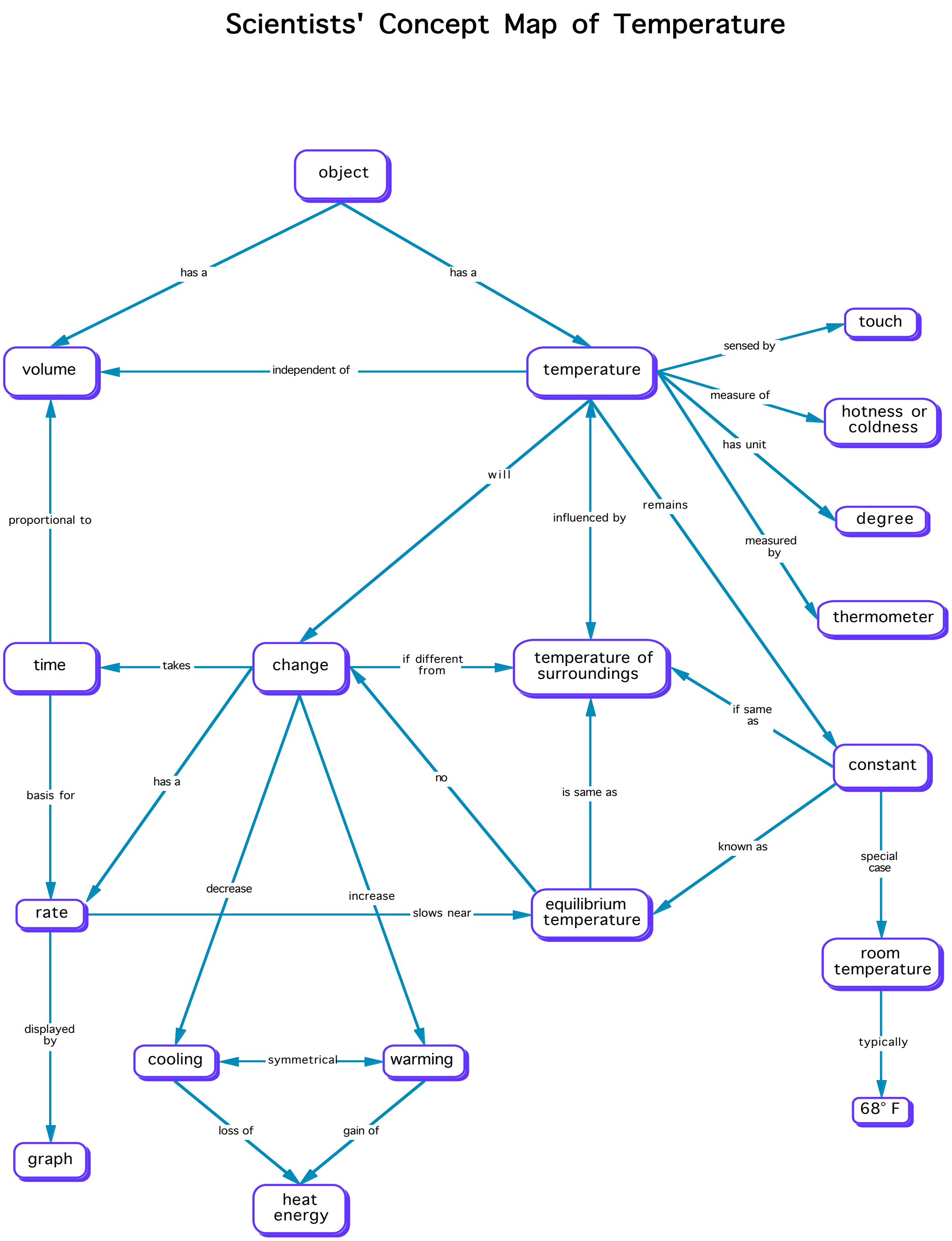
6. **Time for Change of Temperature**
    6.1. Time - volume connection
    6.2. Change takes time
    6.3. Rate of change
    6.4. Influence by other factors

7. **Nature of Heat**
    7.1. Definition
    7.2. Heat, cold, and temperature
    7.3. Heat travels
    7.4. The effects of heat

8. **Graphing Skills**
    8.1. Graph reading skills
    8.2. Graph interpretation skills

Appendix C

Scientists' Concept Map of Temperature



Appendix D

<u>Bonnie's Conceptual Inventory - Before TM - MBL</u>

1. Description of Temperature

1.1 Temperature is how warm or cold something is.

1.2 Bonnie is not sure what a degree is but uses the term correctly.

1.3 Some objects have temperatures *and some do not* .

1.4 Air has a temperature and this affects objects it surrounds.

1.5 Bonnie does not rely very much on her sense of touch in discussion her conceptions.

1.6 Bonnie sometimes reports temperatures in ranges.

2. **Thermometers**

2.1 A thermometer is used to take your temperature.

2.2 The thermometer has to be in the object whose temperature it is taking.

2.3 Bonnie makes numerous references to taking body temperatures.

3. **Intensive Property of Temperature**

3.1 Different amounts of water would initially be the same temperature if taken from the same source.

4. **Change of Temperature**

4.1 An object's temperature will change when it is put in a place with a different temperature.

4.2 *Air plays an important role in cooling and warming the soda in the bottles.*

4.3 Warming is similar to cooling.

4.4 Terms used most often are 'get cooler' and 'get warmer'.

4.5 A soda bottle is more obviously 'in something' when it is in water than when it is in air.

5. Equilibrium Temperature

5.1 The final temperature of an object has a lot to do what the temperature is around it *but will most likely not be the temperature of the surroundings.*

5.2 *Blocking the air from reaching a liquid is the major reason the liquid does not reach the temperature of its surroundings.*

Other reasons include thermal barriers made of plastic and egg shell.

5.3 *Air plays a significant role in determining the final temperature of a liquid after it changes temperature.*

5.4 Room temperature is the *normal* temperature of a room.

6. **Time for Change of Temperature**

6.1 Warming and cooling times depend on the size of the V8 Juice cans *but warming and cooling times are independent of the amount of liquids in bottles. Warming and cooling times are shorter for larger amounts of water in open glasses.*

6.2 Temperature change takes time.

6.3 Temperature change happens at a rate or pace.

6.4 The common final temperature is more important than the size in determining the time it takes for a temperature change.

6.5 *Water higher up in a glass appears closer to the air above it than water that is lower in a similar glass. Since warming times are related to contact with air, the water that is higher in the glass will warm quicker than the water that is lower in a similar glass.*

7. **Nature of Heat**

7.1 *Heat basically is air.*

7.2 A heater makes the temperature get warmer.

7.3 *Heat travels and pushes itself through and into potatoes.*

7.4 Heat warms things.

8. **Graphing Skills**

8.1 Bonnie's graph reading skills were adequate.

8.2 Bonnie correctly interpreted the graph.

References

Appleton, K. (1984). Children's ideas about hot and cold. Learning in science project (primary). Hamilton, New Zealand: Waikato University, Science Education Research Unit. (ERIC Document Reproduction Service No. ED 252 407)

Confrey, J. (1990). A review of the research on student conceptions in mathematics, science, and programming. In C.B. Cazden (Ed.), Review of Research in Education (pp.3 -56). Washington D.C: American Educational Research Association.

Driver, R., & Erickson, G. (1983). Theories-in-action: Some theoretical and empirical issues in the study of students' conceptual frameworks in science. Studies in Science Education, 10(1983), 37-60.

Driver, R.., Guesne, E., & Tiberghien, A. (1985). Childrens' ideas in science. Philadelphia: Open University Press.

Erickson, G.L. (1979). Children's conceptions of heat and temperature. Science Education, 63(2), 221-230.

Krajcik, J.S., & Layman, J.W. (1989). Middle school teachers' conceptions of heat and temperature: Personal and teaching knowledge. Paper presented at the annual meeting of National Association for Research in Science Teaching, San Francisco.

Lewis, E.L., & Linn. M.C. (1989). Heat energy and temperature concepts of adolescents, naive adults, and experts: implications for curricular improvements. Paper presented at the annual meeting of National Association for Research in Science Teaching, San Francisco.

Linn, M.C., & Songer, N.B. (1988). Curriculum reformulation: Incorporating technology into science instruction. Paper presented at the annual meeting of American Education Research Association, New Orleans.

Linn, M.C., Songer, N.B., Lewis, E.L., & Stern, J. (1990). Using technology to teach thermodynamics: Achieving integrated understanding. In D.L. Ferguson (Ed.), Advanced technologies in the teaching of mathematics and science. Berlin: Springer-Verlag.

Lorsbach, A.W. & Tobin, K. (1992). An interpretation of assessment methods in middle school science. International journal of science education. 14(3), 305 -.

Novak, J.D., & Gowin, D.B. (1984). Learning how to learn. Cambridge: Cambridge University Press

Osborne, R., & Freyberg, P. (1985). Learning in science - the implications of children's science, Auckland: Heinemann.

Posner, G.J., & Gertzog, W.A. (1982). The clinical interview and the measurement of conceptual change. Science Education, 66(2), 195-209.

Roller, D. (1950). The early development of the concepts of temperature and heat. Harvard case Histories in Experimental Science. Cambridge: Harvard University Press.

Shayer, M., & Wylan, H. (1981). The development of the concepts of heat and temperature in 10-13 year-olds. Journal of Research in Science Teaching, 18(5), 419-434.

Stavy, R., & Berkovitz, B. (1980). Cognitive conflict as a basis for teaching quantitative aspects of the concept of temperature. Science Education, 64(5), 679-692.

Stewart, J. (1980). Techniques for assessing and representing information in cognitive structure. Science Education, 64(2), 223-235.

Wiser, M. (1987). The uses of MBL, simulations, and kinetic molecular models to teach thermal physics. Paper presented at the annual meeting of American Education Research Association, Washington, D.C.

Wiser, M. & Carey, S. (1983). When heat and temperature were one. In D. Gentner & A.L. Stevens (Ed.), Mental models (pp.267-298). Hillsdale, NJ: Lawrence Erlbaum Associates.

Wiser, M., & Kipman, D. (1988). The differentiation of heat and temperature: An evaluation of the effect of microcomputer models on students' misconceptions. Technical Report 88-20. Cambridge, MA: Technical Education Research