# An attempt to overcome alternative conceptions related to heat and temperature



1995 Phys. Educ. 30 19

(http://iopscience.iop.org/0031-9120/30/1/004)

# An attempt to overcome alternative conceptions related to heat and temperature

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**A teaching model aimed at promoting conceptual change concerning the concepts of heat and temperature is described. The type of research conducted seems to have great impact on the professional development of the secondary school teachers who participate in the project.**

Concepts related to heat and temperature are renowned for presenting students with conceptual problems. Research findings, involving secondary school students before formal teaching and university students enrolled in science degrees, give evidence that the use of the traditional approach concerning these concepts does not promote conceptual change. In an attempt to overcome this situation an alternative approach to the teaching of heat and temperature at an introductory level has been designed and implemented. The teaching model has an underlying constructivist perspective and the proposed changes to the traditional approach have been based on the research findings cited above.

The study has been conducted by two university teachers and two secondary school teachers. The findings suggest that the model has potentialities for promoting a better understanding of the phenomena concerning heat and temperature.

In the whole process the role of action research involving the two categories of teachers, acting as researchers, was also analysed and proved to be a very useful and efficient activity for in-service teacher education.

### Introduction

Teaching has been described (Zumwalt 1982) as a deliberative process requiring teachers to see and think about what they do. Khun (1986) points out that 'a long and distinguished theoretical literature in the field of education, which may be traced to the beginning of the century, reflects the opinion that the only way to improve teachers' thinking is to involve them in it'. On the other hand, over the last two decades a large number of studies have been conducted on alternative conceptions in physics (e.g. Driver 1981, Gilbert and Watts 1983, McDermott 1984, Maurines 1992). These studies have given strong evidence of the importance of those ideas in the understanding of key concepts in physics.

One of the topics to be covered in the secondary school physics curriculum concerns the introduction of thermodynamics, or more precisely thermometry. In Portugal this has been allocated to the 9th grade (14-15 years old). However, studies conducted with science university students, by one of us, show that many of these students held ideas related to heat and temperature similar to those held by children before formal teaching or even adults whose formal science education finished at the 9th grade.

In the domain of thermodynamics a number of studies have been made on the ideas that students have about heat and temperature (e.g. Erickson and Tiberghien 1985, Clough and Driver 1985). The following alternative conceptions among pupils answering qualitative questions have been noted.

(i) Many pupils seem to believe that heat is a kind of substance residing in objects, which can move through them and can pass from one to another. This has sometimes been reinforced by textbooks.

(ii) Most pupils discriminate insufficiently between heat and temperature. For them, temperature is a property of the material from which a body is made and is a measure of heat.

(iii) Pupils tend also to reason that different sensations mean different temperatures, and the concept of thermal equilibrium, taken for granted by teachers and textbook writers, is not held by the majority of pupils. When in contact with its surroundings, the temperature of an object is seen, by a large number of students, to be dependent primarily on the substance from which the object is made.

(iv) Many pupils think that heating a body always means increasing its temperature. The temperature of a phase transition is not considered as a characteristic of a pure substance.

(v) The temperature of a phase transition is seen, by many pupils, as the maximum temperature that a substance can have when it is heated.

Clough and Driver (1985) suggest that 'the students' alternative perspectives have not been noticed before because of the way teaching is conceptualized and carried out'. Nevertheless, as pointed out by Rowell *et al* (1990), while there has been a wealth of published research identifying students' ideas about scientific concepts, relatively little has appeared detailing how alternative conceptions might best be changed and why proposed strategies are expected to work.

On the other hand, there is great evidence that the success or failure of any curriculum implementation depends first of all on the way teachers see it. The implementation can be seen by teachers as a process externally imposed on them, and the probability of failing is then very high, or it can be seen as a process in which teachers are genuinely interested, in whose development they are very much involved and about which they have reflected and discussed in depth. The implementation has a greater chance of success in the latter situation.

Sharing Khun's views, the present study was conducted on the design and implementation of a teaching model aimed to overcome alternative conceptions on heat and temperature. The study was undertaken with mixed ability pupils in the normal physics context of the secondary school teachers' classes.

## The study

The study consists of three phases. In the first phase the two secondary school teachers, from the same school, came to the university for several sessions, during which they were introduced to the issue of alternative conceptions. A review of the literature on this topic, and a joint reflection and discussion on it, helped them to become acquainted with the problem.

In the second phase (the school year 1991/92), and before formal teaching on phenomena related to heat and temperature, a first diagnostic questionnaire (a pre-test, on pupil's ideas about these concepts) was designed and given to 92 students - 79 from the teachers' classes and 13 from another teacher's class in the same school but not involved in the study. The latter provided a control class. Each student was required to make a choice response and to give a reason for it. This was considered essential because the reason provided gives an idea of the logic used and of any alternative conception. The last question was an open one asking for students' ideas about the concepts of heat and temperature.

On the basis of the analysis of the questionnaire results, the team used various sessions to develop the teaching model. This model was then implemented by the teachers in their classes. Meanwhile, a post-test was designed with the same objectives as the first one, in order to be given at the end of the implementation. Ten lessons by each teacher were video recorded and analysed by the team. Various reflection sessions then took place. These sessions were very important for both the university and the secondary school researchers since they provided opportunities for interesting discussions on the events that happened in the lessons (either scientific or pedagogical) and they also allowed a more in-depth discussion about the scientific aspects involved.

This first study was used not only as a pilot study but also as a means to promote a training period for the secondary school teachers, who acted as researchers for the first time in their professional lives.

In the third phase (the following year 1992/93) a new cycle took place, based on the findings of the first implementation, and the results of this will be presented here.

Some modifications were made: the control class was chosen from a different school in the city's neighbourhood in order to avoid any interference with the implementation. It was decided to follow only one class of each secondary school teacher. The pre-test was applied to 48 students in the experimental classes and to 31 students in the control class.

## Outline of a teaching model for the teaching of heat and temperature

One of the most impressive findings of the content analysis of the pre-test responses was the fact that students revealed a great difficulty in accepting that different objects are at the same temperature when in contact with the same surroundings for a long time. The temperature of an object is seen as a characteristic of the material from which the object is made. This means that the concept of thermal equilibrium, taken for granted by teachers and textbook writers, is not present in the majority of the students (91.7 - 96.9% in the experimental and control classes respectively).

The concept of thermal equilibrium is a key concept for the study of heat and temperature as it is a mental construct, the understanding of which is a basic prerequisite for many other concepts of thermodynamics. At an introductory level temperature is defined as 'a macroscopic quantity related to the mean kinetic energy of each particle which also determines whether or not two or more ordinary objects are in thermal equilibrium when placed in contact with each other'. Heat has also been defined in terms of thermal equilibrium: 'heat is energy which is transferred from an object at a higher temperature to another at a lower temperature, until they reach the state of thermal equilibrium'.

So this implies that in order to reach the scientific meaning of heat and temperature students must understand correctly what is meant by thermal equilibrium. Nevertheless, there is strong evidence showing that in students' minds the sensation of hotness or coldness felt when touching objects in thermal equilibrium with the same surroundings is synonymous with higher or lower temperature. An analysis of textbooks revealed that this concept of thermal equilibrium has been treated briefly if at all.

On the basis of these findings it was decided to consider thermal equilibrium as the central concept from which all the others would appear, as a necessity to interpreting and understanding it.

The model for the teaching of heat and temperature proposed is based on the constructivist perspective. This model assumes that students are best seen as active constructors of their own knowledge. They are not seen as coming to instruction without prior ideas about the topic in question. Rather, students are likely to have access to ideas derived from informal experience and language usage, which may influence their receptivity to new ideas. This view of learning is particularly valuable in approaching the teaching of heat and temperature.

The important part of this model is the emphasis on the active involvement of the learner in his/her own learning. The information presented to the student is not carried by the information itself. Rather, the student has to give meaning to the information as a result of its interaction with her/his prior knowledge. However, she/he may not be able to make links between 'old' and 'new' knowledge without guidance. It is here where the teaching skills of the science teachers can be used to a great effect.

The framework for the model of teaching aimed at promoting conceptual change was based on Rogers' development model of the adoption process, described elsewhere (Thomaz and Gilbert 1989).

It contains five stages identified in the mental process of adopters of 'new' concepts: (1) awareness,

(2) interest, (3) evaluation, (4) trial and (5) adoption.

The primary function of the awareness stage is to initiate the sequence of later stages that lead to eventual adoption or rejection of the new concepts. Hassinger (1959) points out that information about a new idea often does not create awareness, even though the individual may be exposed to this information, unless the individual has a problem or a need that the new idea promises to solve. The individual must be aware of his own ideas. Presented with situations that he is asked to interpret, there must be dissatisfaction with these existing ideas or conceptions and a desire to change them. At the interest stage the individual becomes interested in the 'new' idea and seeks additional information about it. The function of the interest stage is mainly to increase the individual's information about the 'new' idea that must be intelligible and plausible to him.

A sort of 'mental trial' occurs at the evaluation stage. If the individual feels that the advantage of the 'new' idea outweighs the disadvantage he will decide to try the 'new' idea. At the trial stage the individual uses the new concept in order to determine its usefulness for possible complete adoption.

In the model proposed, the role of the teacher is to create opportunities that can promote the development of these different stages. It is in the adoption stage that a conceptual change can take place.

Table 1 shows the five stages of the model teaching aimed at promoting conceptual change concerning concepts related to heat and temperature and the activities that took place in each stage.

At the awareness stage students are exposed to situations in which they are 'forced' to be aware and use their own ideas for the interpretation of phenomena presented to them in those situations. Students must be presented with situations in which they could:

(i) be aware of their own and peers' ideas concerning sensations and temperature;

(ii) verify that different sensations do not mean different temperatures;

(iii) recognize that temperature is not a characteristic of each substance (when in the same surroundings an object made of metal is at the same temperature as an object made of wood);

(iv) recognise that, whether objects are of the same material or not, when put in contact a final state is reached in which the reading of the thermometer is the same.

In the first step students should have opportunities to become aware that different sensations do not mean different temperatures. For that, the teacher starts the lesson by asking students to touch different objects in the room and to discuss the sensations felt. Then students are invited to give their ideas about the temperature of each object. Students use here their familiar term of temperature. After this first set of questions, students should be offered opportunities to measure the temperature of a set of objects brought by the teacher. These objects should be in

**Table 1.** The five stages of the model and the activities that took place in each.

| Stage | Activities |
|---|---|
| Awareness | 1st step: Awareness of pupils' own ideas about sensations and temperature. (Experimental) |
| | 2nd step: Exposure to conflicting situations - temperature measurement of different objects in contact with the same surroundings. (Experimental) |
| Interest | 3rd step: Understanding temperature in microscopic terms. (Experimental) |
| | 4th step: Understanding heat as energy transferred at the microscopic level. |
| Evaluation | 5th step: Interpretation of thermal equilibrium. |
| Trial | 6th step: Use of thermal conductivity to explain why different sensations do not mean different temperatures. (Experimental) |
| | 7th step: Reinforcing the discrimination between heat and temperature using the interpretation of phase transitions. (Experimental) |
| Adoption | 8th step: Relationship between heat and temperature variations. (Experimental) |
| | 9th, 10th, ... : Discussions, tests, problems, etc, that can promote the generalization of the concepts and the appreciation of their range of application. |

the room from the beginning of the lecture (for instance, a glass of water at room temperature, a piece of cotton wool, a glass full of ball bearings, a block of wood, etc. Care must be taken to choose objects whose temperatures are easy to measure with simple thermometers existing in the school). This activity functions as an opportunity to promote conflict situations.

A situation should be provided in which two objects at different temperatures are brought into contact, allowing students to read the thermometer regularly until thermal equilibrium is reached.

The discussion that follows should involve all the students and the talk should be referred to the household situation, drawing conclusions relevant to daily life. The awareness stage should take place in classes of one or two periods.

Once in conflict with the existing ideas, students must be motivated to seek new information about temperature and heat. In this interest stage, experiments should be provided in which students can visualize the effects of heating air contained in a tube (on its volume and pressure). A dynamic model, in which the increase in volume and pressure can be visualized in terms of the increase in mean kinetic energy, should be used here. Students are then asked to interpret the temperature change between two objects in terms of energy change.

Only after this should the term heat be given as energy transferred between objects in contact with each other or through a medium until thermal equilibrium has been reached.

To promote the evaluation stage, students should be asked to evaluate the use of these 'new' concepts in the interpretation of thermal equilibrium in a day-to-day context.

The introduction of the concept of thermal conductivity appears as a necessity to explain why different sensations do not mean different temperatures. This should be done experimentally. Also, experiments involving phase transitions should take place in order to promote the development of the trial stage and help the reinforcement of the discrimination between heat and temperature.

The next activities should be used by the teacher as a means to promote the adoption stage as well as to certify that it has been accomplished. These activities should involve the quantification of the relation between heat and temperature variations (always through experiments), discussions, problem solving, tests, etc.

## Results

The study provides two main results: (i) the potentialities of the model for promoting a better understanding of phenomena involving heat and temperature, and (ii) the implications of this type of study on the professional development of the teachers working at the secondary school level.

**The potentialities of the model for promoting a better understanding of phenomena involving heat and temperature.**

The analysis in this case involved an examination of the data, gathered through the pre- and post-tests, for evidence of clusters of statements that could reveal the existence of alternative conceptions held by the students. The comparison of data between the two types of classes (experimental and control) provided the baseline for assessing the effectiveness of the teaching model.

The pre-test about heat and temperature allowed the identification of students' conceptions that were similar to those cited in the literature and indicated that a great proportion of students, in both cohorts, held ideas about phenomena related to heat and temperature prior to instruction that were not consistent with accepted scientific explanations. The prevalence of these conceptions in the pre-tests of both cohorts and in post-tests following teaching is presented in table 2.

As can be seen from table 2, before teaching, the great majority of students in both types of classes did not hold the concept of thermal equilibrium. For them, temperature is a property of the materials from which the objects are made and objects in contact for a long time with the same surroundings have different temperatures if their materials are different. After teaching according to the model designed, the percentages of students presenting these ideas decreased from 93.8 to 18.7 and 91.7 to 20.8 respectively, while the percentages of those taught according to the traditional model decreased only from 96.9 to 72.7 and 96.9 to 76.6 respectively.

The percentage of students who presented the idea that heat or cold is a kind of substance residing in objects decreased from 31.3 to 6.3 in the

**Table 2.** Results of the analysis of the data of the pre- and post-tests applied to the two experimental classes and to the control one.

| Students' conceptions | Percentage of students | | | |
|---|---|---|---|---|
| | Experimental class | | Control class | |
| | pre-test ($n = 48$) | post-test ($n = 48$) | pre-test ($n = 31$) | post-test ($n = 30$) |
| Heat or cold as a substance residing in objects | 31.3 | 6.3 | 58.1 | 56.7 |
| Temperature is a property of the substance from which the body is made | 93.8 | 18.7 | 96.9 | 72.7 |
| Temperature is something that can be transferred | 14.6 | 6.3 | 19.4 | 30.0 |
| Objects in contact for a long time with the same surroundings have different temperatures if their material is different | 91.7 | 20.8 | 96.9 | 76.6 |
| The state of hotness or coldness depends on the material from which the body is made | 67.7 | 6.3 | 66.7 | 53.3 |
| Temperature is a measure of a body's heat | 39.6 | 8.3 | 29.0 | 36.6 |
| Heat is sensation | 41.7 | 14.6 | 25.8 | 66.7 |
| Temperature is a function of heat | 29.2 | 2.1 | 32.3 | 32.3 |

experimental classes, while in the control class it remained almost unaffected.

An interesting situation is the fact that in the control class some ideas appeared reinforced after formal teaching, like the ideas that 'temperature is something that can be transferred' (19.4 before and 30.0 after teaching), 'temperature is a measure of the body's heat' (29.0 before and 36.6 after teaching) and 'heat is a sensation' (25.8 before and 66.7 after teaching). In this last case the idea that heat is a sensation seems to be an elementary state of the concept, previous to the scientific one.

The last question of the questionnaires was an open one in which students were asked to explain to another person what they meant by heat and temperature. Before teaching, none of the students, either in the experimental or in the control class, displayed a scientifically acceptable idea. After teaching according to the model designed, the percentage of students able to give a correct idea of heat, rose from zero to 66.7, while in the control class none of the students were able to do that. Nevertheless, as far as the concept of temperature is concerned, although no change took place in students' ideas in the control class, the improvement displayed by the students of the experimental class was less evident than that observed with the heat concept. Only 37.5% of the students gave an acceptable idea of temperature. The concept of temperature in microscopic terms seems to be more difficult to assimilate than the concept of heat and it needs more evidence and more time to be learned properly. Although it is too early to say how successful the model is, the analysis of the data gives some encouraging results.

**The implications of this type of study on the professional development of secondary school teachers.**

The data in this case were gathered through informal interviews with the teachers and from a written report elaborated on by them, with the result of their reflection on the work developed during this study.

According to them, this work was very rewarding and highly fruitful. The main aspects they thought that most created these feelings are:

(i) the interchange of experiences between university and secondary school teachers, the latter not being mere performers;

(ii) the reading and discussion of studies on students' ideas about heat and temperature made by other researchers in other countries, which allowed for an awareness of the implications on the students' thinking and learning processes;

(iii) the acquaintance with techniques for the identification of students' ideas, which allowed the development of skills for the elaboration of diagnostic tests and ways of analysing the data gathered;

(iv) the implementation of new instructional strategies for the purpose of promoting conceptual change, which opened new avenues for their performance as teachers;

(v) the possibilities for observations of the performances of their colleagues as well as of themselves, which helped them to improve some aspects of their teaching that had been undetected before.

**Conclusion**

The teaching model described in this study appeared to be successful in changing many students' ideas about situations related to fundamental ideas about heat and temperature. In particular the ideas that temperature is a property of the substance from which a body is made and that different sensations mean different temperatures changed, in the great majority of students taught according to this model, towards the scientific explanation, while the same ideas, also held by the students of the control class, taught by the traditional approach, were almost unaffected. This change promoted the understanding of the concept of thermal equilibrium, considered to be a key concept for the study of phenomena related to heat and temperature.

The findings revealed an improvement over the usual teaching approach which, as shown by results, left students' own ideas almost unaffected. Nevertheless, as research suggests that students' ideas tend to revert to their prior ideas after a period of time, a delayed post-test would be necessary to indicate that the scientific conceptions are retained. This calls for further investigation.

The secondary school teachers found that using the new teaching approach resulted in better learning conditions and better learning outcomes. They also found that the way the study took place, involving them in the research, contributed greatly to their professional development. It helped and motivated them to reflect more accurately on their own practice. The way the study has been conducted strengthens substantially the link between research, theory and practice. For the university researchers it promoted a deep understanding of the problems involved in classroom practice, not only through the discussions that took place when elaborating the teaching model and the planning of the strategies used, but also when analysing the video-recorded classes. This type of action research proved to be a very useful and efficient activity for in-service teacher education either for secondary school teachers or for university teachers involved in teacher training.

**Appendix**

Examples of items from the pre-and post-tests used to address students' conceptions related to heat and temperature.

*Question 1*

At bedsides there are usually woollen rugs that you can put your feet on when getting out of the bed.

1.1 How do you explain the different sensations you feel when putting your feet either on a stone floor or on a woollen rug?

1.2 If you could put thermometers in close contact with the stone of the floor and with the wool of the rug you would expect that:

- the temperature of the stone was higher than that of the wool;
- the temperature of the stone was lower than that of the wool;
- the temperature of the stone was practically the same as that of the wool.

Explain your answer.

*Question 2*

Two objects made of different materials - one of iron and the other of wood were put into an oven at 60 degrees C.

After a certain period of time Mary measured the temperature of both. Mary found:

- the temperature of the wooden object higher than that of the iron one;
- the temperature of the wooden object lower than that of the iron one;
- the temperature of both objects to be the same.

Explain your answer.

*Question 3*

Two spoons, one made of metal and the other made of plastic, were dipped into a mug of very cold water.

3.1 If you felt the handles of the spoons you would feel:

- the metal spoon hotter than the plastic one;
- the metal spoon colder than the plastic one;
- the same sensation in both.

Explain your answer.

3.2 If you measured the temperature of both spoons you would find:

- the temperature of the metal spoon higher than that of the plastic one;
- the temperature of the plastic spoon higher than that of the metal one;
- the same temperature in both.

Explain your answer.

*Question 4*

Imagine you have been asked to explain to another person what is meant by heat and what is meant by temperature. What would you say?

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