JOURNAL OF BALTIC SCIENCE EDUCATION

ISSN 1648-3898

GRAMMAR SCHOOL STUDENTS' MISCONCEPTIONS CONCERNING THERMAL PHENOMENA

Petr Kacovsky

Abstract. *This study describes a research focused on grammar school students' misconceptions in the context of common, everyday thermal phenomena. Almost 500 Czech grammar school students from 24 classes were asked to fill in the reduced version of the Thermal Concept Evaluation in order to measure the asset of traditional instruction in eliminating scientifically incorrect ideas; the reached normalized gain of 0.23 signalizes poor effectiveness of instruction as a whole. In some areas, Czech students' results were quite poor (questions dealing with phase transitions), while other ones turned out to be surprisingly good in comparison with foreign studies (e.g. perception of "cold" as a scientifically disproved concept). Besides questions regarding thermal phenomena, the test included four statements designed for studying possible relationships between students' scores and their attitudes. Those who declared "fondness for physics" showed better results both in the pre-test and the post-test; however, the normalized gain turned out to be independent of the attitudes established.*

Key words: *heat and temperature, grammar school students, misconceptions, Thermal Concept Evaluation, thermal phenomena.*

Petr Kacovsky
Charles University in Prague, Czech Republic

Introduction

In his work *An essay concerning human understanding* (Locke, 1690), the famous English seventeenth century philosopher John Locke suggested that students come to school as *tabula rasa* (blank slates) and it is completely up to the teacher to impart important knowledge and skills to them; in the 20th century, some attributes of this theory were implemented in the behaviourist educational approach. However, in the recent forty years the most commonly embraced learning theory of today, constructivism (Piaget, 1928; Piaget, 1952), has shown that Locke was wrong. Since the mid-1970s, educational researchers spurred by Piaget's work have begun to acknowledge that even the youngest children usually enter the classroom with robust non-traditional ideas and common sense understanding of their natural environment (Read, 2004; Wenning, 2008) – so called preconceptions.

Terminology

Different educational researchers perceive this term – preconceptions – differently. Most commonly, preconceptions are defined as "all ideas held before instruction" (Clement, Brown & Zietsman, 1989) or "ideas that don't have the status of generalized understandings characteristic for conceptual knowledge" (Ausubel, 1967). On the other hand, some authors openly acknowledge the lack of consensus regarding the meaning of the term "preconceptions" (Fisher, Williams & Lineback, 2011; Read, 2004).

Many educational researches affected by the constructivist learning theory focused on studying those unscientific preconceptions, which are inconsistent with a scientific view of the world – misconceptions. Although this term is commonly used and usually well understood, for some authors it evokes different negative connotations (Leihonen, Asikainen & Hirvonen, 2013), which results in many articles that extensively deal with looking for its more suitable equivalents, such as alternative conceptions (Hewson & Hewson, 1984), alternative frameworks (Driver, 1983), naive conceptions

(Harrison, Grayson & Treagust, 1999), naive theories (Resnick, 1983), etc. In this paper, the standard term "misconceptions" will be used in the Clement's context (Clement, Brown & Zietsman, 1989) because of its widespread use and familiarity (Hammer, 1996).

Misconceptions Research

Many well-documented studies conducted in the past 35 years have shown the existence and strong resilience of students' misconceptions in science education independently of the country, type of school and students' age (Driver, Guesne & Tiberghien, 1985; McDermott, 1993; Lewis & Linn, 1994; Osborne & Freytag, 1985; Pfundt & Duit, 1991; Posner, Strike, Hewson & Gertzog, 1982; Wiser & Amin, 2001).

All the main fields of physics (mechanics, electricity, magnetism, optics, thermodynamics…) have been analysed from the perspective of students' misconceptions, often using different concept inventories such as *Force Concept Inventory* (Hestenes, Wells & Swackhamer, 1992), *Conceptual Survey in Electricity and Magnetism* (Maloney, O'Kuma, Hieggelke & van Heuvelen, 2000) and many others. The feeling that all students' difficulties have already been identified results in the fact that voices appear calling for the termination of the misconceptions research (Maskiewicz & Lineback, 2013). On the other hand, in many countries – including the Czech Republic – the misconceptions research became popular much later than in the Western Europe or in the North America so in this context, it can play an important role in increasing awareness of the existence of students' misconceptions among common teachers.

Misconceptions Related to Thermal Phenomena

In terms of misconceptions, thermodynamics does not seem to have been explored as much as e.g. mechanics or electricity and magnetism (Pathere & Pradhan, 2011).

In general, thermodynamics is conceptually a very rich area and it uses many terms that are familiar from everyday life, but have different meanings in physics (Driver, Guesne & Tiberghien, 1985; Leihonen, Asikainen & Hirvonen, 2013). This language gap between the unscientific and scientific approaches together with our everyday experience with common thermal phenomena are responsible for constructing a belief system that is often in conflict with scientifically correct explanations (Luera, Otto & Zitzewitz, 2005).

Typical misconceptions related to thermal phenomena were identified by many researchers (Erickson, 1979; Harrison, Grayson & Treagust, 1999; Kesidou & Duit, 1993; Lewis & Linn, 1994, etc.), and their brief list is given in the Table 1. More extensive reviews of misconceptions-oriented studies in this field were summarized by McDermott & Redish (1999) and Sözbilir (2003).

Table 1. Typical misconceptions in thermodynamics – summary of previous findings (Chu, Treagust, Yeo & Zadnik, 2012; Lewis & Linn, 1994; Sözbilir, 2003; Yeo & Zadnik, 2001).

Topic	Misconception
Heat	There is something like "hot heat" and "cold heat". Heat is a material substance. Heat is proportional to temperature. Heat rises, travels upwards. Heat and cold flow like liquids. Object can "own" a certain amount of heat.
Temperature	Temperature is an extensive quantity, while heat is an intensive quantity. Temperature of boiling water can exceed 100 °C during boiling. Temperature is a measure, an amount of heat. Temperature of an object depends on its size. Temperature will change during melting or boiling.
Heat conductivity & thermal equilibrium	Metals attract, hold or store heat and cold. Wool warms things up. Skin or touch can determine temperature. Some substances (e.g. metals) are naturally colder than others (e.g. wood). The temperature of different objects is different, even though they have been in the same room for a long time.

ISSN 1648–3898

Motivation to Conduct the Study

As stated in the previous paragraphs, there is a lack of representative studies concerning students' misconceptions in the Czech environment; if there are any, they mainly focus on the field of mechanics. Therefore, to get an overview of typical students' difficulties, we often take over the results of studies carried out in the Anglo-Saxon context. However, educational systems, their traditions and regularities are different in the Central and Eastern Europe resulting in obvious questions: What are typical difficulties of Czech students in the field of thermal phenomena? Are they really the same as those summarized in literature? These questions were a major motivation to start this research.

Research Methodology

General Research Background

From the methodological point of view, the quantitative approach was used to solve the research problems. The basic research plan was an ex-post-facto study, with the data gathered by the methods of achievement test and questionnaire.

Sample Selection

The research was focused on grammar school students undergoing physics courses as a part of general education program. Since the physics curricula of different grammar schools are quite similar in the Czech Republic, students typically deal with the topic of thermal phenomena in Year 11, exceptionally in Year 10. This uniformity results in the fact that the participants of this research ranged between the ages of 16 and 18.

About 45 randomly chosen Czech grammar schools (called "gymnázium" in Czech) were addressed to participate in this research; approximately one third of them agreed.

Research Tool

As a research tool, the *Thermal Concept Evaluation* (TCE; Yeo & Zadnik, 2001) was used. This concept inventory was developed by Shelley Yeo and Marjan Zadnik at Curtin University in Perth (Australia) in 2001 and it was, according to the authors, "specifically designed to assess a wide range of beliefs or understandings about thermodynamic concepts held by students aged from 15 to 18." (Despite this authors' note, some researchers (Alwan, 2011; Luera, Otto & Zitzewitz, 2006) later used TCE in their university-oriented research.) The inventory consists of 26 multiple-choice questions typically inspired by common, everyday situations (in the household, at school, on a trip, etc.); many of these questions model a conversation occurring between adolescents. Authors intentionally did not use diagrams and illustrative pictures to avoid misinterpretation in question assignments. Since its creation in 2001, TCE (both in its full and reduced or extended version) has been used in countries all over the world – among other ones in the United States (Luera, Otto & Zitzewitz, 2006), Turkey (Baser, 2006), Libya (Alwan, 2011) or South Korea (Chu, Treagust, Yeo & Zadnik, 2012).

The Czech translation of TCE was completed in March 2013 and consequently discussed with ten experts in physics education and experienced Czech grammar school teachers. The pilot study conducted on a sample of 72 grammar school students in May 2013 resulted in a reduction of TCE to its present form, which includes 19 multiple-choice questions (with respect to the specifics of the Czech education system, questions number 12, 13, 14, 15, 20, 21 and 26 originally involved in TCE were excluded). In the text below, this reduced version of TCE is abbreviated as CTCE (Czech TCE) and its English version is shown in the Appendix to this paper. Since the CTCE questions are too long to be stated in full in the text, their short reformulations partly adopted from Luera, Otto & Zitzewitz (2005) are used below (Table 2).

Besides CTCE questions regarding thermal phenomena, the research tool includes a short questionnaire consisting of four attitudinal questions appended to obtain additional information about the tested students. The purpose of these questions is to look into possible relationships and correlations between students' scores and their attitudes towards physics. This component of the study is discussed in detail in the final part of the following section.

Procedure

The study was designed to use the above-mentioned CTCE as a pre-test and post-test tool, the pre-test being administered before students started the topic of heat and thermodynamics in their regular physics lessons and the post-test being administered immediately after that.

In all participating schools, the pre-test was administered in September and October 2013; the post-test timing depended on the particular school, or more precisely on the particular teacher – generally, the goal was to introduce the post-test no later than two or three weeks after the students had finished the topic of thermal phenomena in their lessons. To fill out both the pre-test and the post-test, students were given 30 minutes; however, the majority of them finished earlier (after about 25 minutes).

To match the pre-test and the post-test of each investigated participant in order to compare them, students were asked to sign their answer sheets; if they refused to do so (only in a few rare cases), they were asked to mark their answer sheet with their nicknames or some number.

In order to provide the participants from different schools and classes comparable conditions for completing the test, almost all tests (with two exceptions) were administered by the researcher himself. This approach helped to exclude the influence of teachers' personalities and their attitudes towards the research, which could be both demotivating (the teacher depreciating the test) and stressful (the teacher overestimating it) for the students. The fact that personal presence in classrooms could help the researcher to observe which questions are most time consuming or which are typically skipped over during the first reading can be considered an additional benefit.

Data Analysis

Eventually, 23 classes from 16 schools were involved in the pre-test and 586 of their students taught by 20 different teachers participated in filling out CTCE. Almost 84% of these students, strictly speaking 492 participants, filled out both the pre-test and post-test, which provides a statistical sample for the comparison between the pre-test a post-test scores. For each question, the normalized gain (Hake, 1998) and index of item discrimination (Yeo & Zadnik, 2001) were calculated.

Results of Research

General Data

As mentioned above, the data collected from 492 respondents (287 girls and 205 boys) were processed by statistical methods. The average score reached by students was 45.4% correct answers in the pre-test and 57.9% in the post-test, resulting in a normalized gain of 0.23. The boys' results were better than the girls' ones, both in the pre-test (by 14%) and the post-test (by12 %); however, the normalized gain was almost the same for both groups. Only questions number 10 and 12 (see Appendix) showed a normalized gain higher than 0.30 (more specifically 0.44 and 0.38), which is considered to be a borderline for medium effective instruction, while other questions can be classified as *"low-g"*.

Depending on the question, the ratio of correct answers ranged between 19.5% (question 11) and 80.5% (question 16) in the pre-test, thus pointing to an adequate *p*-value, which determines the item difficulty and should not be lower than 20% and higher than 90%.

In terms of the test reliability, both the pre-test and the post-test exhibit the same Cronbach alpha of 0.72.

Item Analysis

Table 2 shows the students' results for particular questions – the pre-test and post-test score, normalized gain g and index of item discrimination D (D was determined on the basis of the pre-test, $N = 586$).

Table 2. Results of TCE – pre-test and post-test comparison (*N* = 492).

No.	Question	Pre-test (%)	Post-test (%)	Normalized gain g	Index of item discrimination D
1	Likely temperature of ice cubes in a freezer.	76.8	80.1	0.14	0.32
2	Likely temperature of water in a glass with ice.	51.2	63.4	0.25	0.42
3	Likely temperature of ice cubes in a puddle of water.	43.3	58.5	0.27	0.41
4	Likely temperature of rapidly boiling water.	62.6	73.0	0.28	0.30
5	Temperature of continuously boiling water.	26.0	40.9	0.20	0.32
6	Temperature of steam above the boiling water.	22.6	28.7	0.08	0.09
7	Temperature of a mixture of unequal volumes of water of different temperatures	79.1	82.9	0.18	0.23
8	Reason behind water boiling at a high altitude.	35.8	51.4	0.24	0.66
9	Likely temperature of a plastic bottle and a can of coke.	36.4	48.0	0.18	0.51
10	Reason why a counter under coke can feel colder than the rest of the counter.	43.1	68.1	0.44	0.70
11	Equal volumes of water and ice in a freezer, which of them loses more heat?	19.5	43.5	0.30	0.23
12	Explanation why a metal ruler feels colder than a wooden ruler.	38.0	61.4	0.38	0.65
13	Likely room temperature when given wet and dry washcloth tempera-tures.	28.5	31.5	0.04	0.38
14	Reason why a cold carton from a refrigerator feels colder than the one on a counter.	41.7	47.2	0.09	0.59
15	Reason why pressure cookers cook faster than normal saucepans.	32.1	50.8	0.28	0.53
16	Reason why bike pump becomes hot.	80.5	85.8	0.27	0.20
17	Why do we wear sweaters in cold weather?	58.5	69.7	0.27	0.59
18	Wooden ice pop sticks are warmer than ice part.	34.3	48.2	0.21	0.73
19	The lowest possible temperature.	53.0	66.1	0.28	0.60
	Total (N = 492)	45.4	57.9	0.23	-
	Total girls (N = 287)	39.7	52.8	0.22	-
	Total boys (N = 205)	53.4	64.8	0.24	-

Phase transitions. According to Table 2, the most problematic items for students were questions number 5, 6, 11 and 13, having all scored below 30% in the pre-test; despite a slight improvement after the instruction, all these questions remained the four worst answered in the post-test. In addition, two of them, questions number 6 and 13, had absolutely the lowest value of normalized gain (both under 0.08). Since all these questions deal with phase transitions (or with related temperature changes, more precisely), it is natural to focus on this part of thermal physics –Table 3 shows the four strongest misconceptions identified using CTCE, all being part of the topic of phase transitions. It is notable that the ratio of respondents who had thought that the steam above boiling water must exceed the temperature of 100 °C slightly increased after the instruction.

Table 3. Misconceptions identified in the field of phase transitions.

Question No.	Misconception	Ratio of students holding this misconception	
		Pre-test (%)	Post-test (%)
3	The temperature of ice cubes in a room must be above 0 °C.	50.2	36.1
5	The temperature of continuously boiling water exceeds 100 °C.	71.8	57.5
6	The steam above boiling water exceeds the temperature of 100 °C.	58.7	61.0
11	It is impossible to get water at 0 °C.	43.7	23.2

The concept of cold. According to previous studies, the belief that heat and cold are antonyms, two different phenomena occurring in different situations, survives in many students. To confirm or confute this, all statements of CTCE where the term "cold" occurs were (with slight reformulations) extracted to Table 4 and students' gains reached in them in the pre-test and the post-test were compared. Surprisingly, the table shows that in the case of Czech students, the term "cold" probably didn't play an important role in their decision-making, as all items containing this scientifically disproved concept were scored either very low (like items 12e and 17a) or they showed a considerable decrease in the post-test (items 10a, 14a, 14e, 18b).

Table 4. Items of TCE where the term "cold" occurs.

Item	Statement	Chosen by % of students	
		Pre-test	Post-test
10 a	The cold has been transferred from the coke can to the counter.	50.6	24.4
12 e	Cold flows more easily from metal than from wood.	8.5	6.3
14 a	Compared with the warm carton, the cold carton contains more cold.	17.9	7.5
14 e	Compared with the warm carton, the cold carton conducts the cold more rapidly to Pavel's hand.	10.2	3.9
17 a	We wear sweaters to keep the cold out.	1.6	1.0
18 b	Ice contains more cold than wood does.	12.2	4.9

Heat as energy stored in matter. Even though Czech textbooks and Czech teachers systematically emphasize the fact that heat is a process quantity, the students' concept of heat as some kind of energy contained inside the matter is very strong and resistant to change. As shown in Table 5, this conclusion was supported by this research as well. All statements of CTCE where the idea that heat is contained in the matter occurs were extracted to this table and as in the previous paragraph, students' gains in the pre-test and the post-test were compared. This comparison showed that the perception of heat as a "property of matter" was either only insignificantly reduced (items 11c and 12c) or even notably strengthened (items 14b and 18c) after the instruction.

Table 5. Items of TCE where the idea that "heat is contained in the matter" occurs.

Item	Statement	Chosen by % of students	
		Pre-test	Post-test
11 c	Both ice and water contain the same amount of heat.	27.6	27.5
11 d	Ice does not contain any heat.	5.9	2.6
12 c	The wooden ruler contains more heat than the metal ruler.	11.6	9.8
14 b	Compared with the warm carton, the cold carton contains less heat.	27.8	39.8
18 c	The wooden sticks contain more heat than ice.	15.0	22.4

Question 6:

What do you think is the temperature of the steam above the boiling water in the kettle?

88 °C
98 °C
110 °C
120 °C

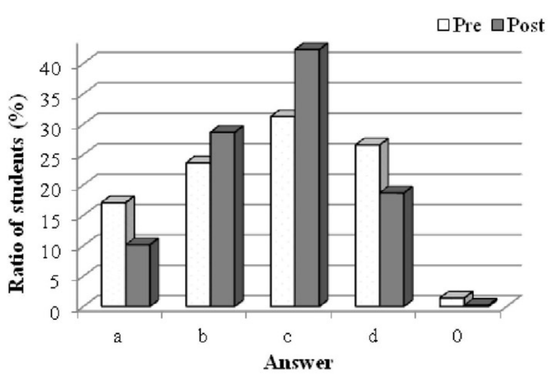

Figure 1: Students' responses to question number 6 ("0" stands for "no answer given").

ISSN 1648–3898

Temperature of the steam. The most serious students' difficulties were identified in responding to question number 6, which deals with the problem of temperature of the steam just above boiling water – in the post-test, only less than 29% of participants chose the correct answer. At the same time, this question showed the second lowest normalized gain (0.08) and the very lowest index of discrimination (0.09), which means that it was impossible to distinguish between high-scoring and low-scoring students – in other words, many students (including those with high total scores) probably simply guessed at the answer. In addition, the belief that the temperature of the steam exceeds 100 °C was even stronger after the instruction. The full statistics concerning this question is summarized in Figure 1.

"Containing" heat and cold. With a normalized gain of 0.09, question number 14 ranks among the items with least improvement after the instruction. At the same time, it represents a typical question where one misconception was replaced with another. By the instruction, the belief that "the box contains more cold" was quite successfully suppressed; however, another wrong conception that "the box contains less heat" was equally strengthened, since the correct answer was chosen by less than a half of the students. The full statistics of question 14 is shown in Figure 2.

Question 14:

Pavel simultaneously picks up two cartons of chocolate milk, a cold one from the refrigerator and a warm one that has been sitting on the countertop for some time. Why do you think the carton from the refrigerator feels colder than the one from the countertop? Compared with the warm carton, the cold carton…

a) … contains more cold.
b) … contains less heat.
c) … is a poorer heat conductor.
d) … conducts heat more rapidly from Pavel's hand.
e) … conducts cold more rapidly to Pavel's hand.

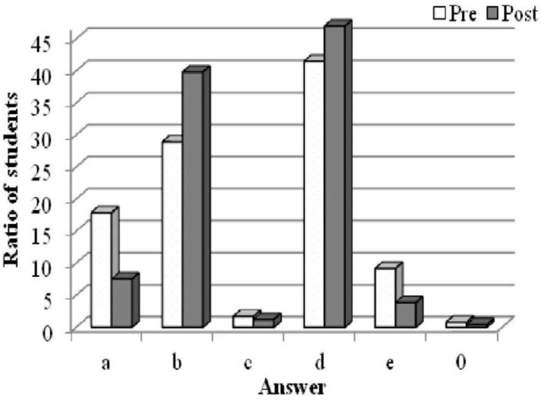

Figure 2: Students' responses to question number 14 ("0" stands for "no answer given").

Attitudinal Questions (Results)

The purpose of the four attitudinal questions attached to CTCE was to look into possible relationships and correlations between students' scores and their attitudes towards physics. On the scale from 1 to 6, the students were asked to express their agreement or disagreement with four statements (S1 to S4); the choice of number 1 meant "I completely agree" while the choice of number 6 stood for "I completely disagree". In Table 6, the average values reached in statements S1 to S4 are summarized and completed with the comparison of boys' and girls' attitudes.

Table 6. Students' attitudes towards physics (the values in brackets stand for standard deviations).

	Statement	Average score *(N = 492)*	Girls' average score *(N = 287)*	Boys' average score *(N = 205)*
S1	I expect I will need physics in the future (at university, at work).	3.82 (1.53)	4.18 (1.49)	3.34 (1.46)
S2	Physics is useful for society.	2.18 (1.12)	2.28 (1.12)	2.05 (1.09)
S3	Physics is useful for me.	3.29 (1.38)	3.54 (1.34)	2.96 (1.35)
S4	I enjoy physics, physics entertains me.	3.83 (1.51)	4.12 (1.44)	3.45 (1.51)

It is immediately obvious that in comparison to boys, girls are generally more critical to physics and its usefulness in general. Nevertheless, it seems that the majority of Czech students appreciate the importance and usefulness of physics for the society as a whole, but they do not regard it as beneficial for themselves. The results in statements S1 and S4 provide quite similar results, which can lead to a hypothesis that students who don't see physics useful for their future are the same as those who don't enjoy it. Such an assumption seems probable, since in 67.5% of respondents (332 students), the numbers given in S1 and S4 statements were the same or differed only by one degree.

As indicated above, the purpose of statements S1 to S4 is to make possible the assessment of the influence of students' attitudes on their CTCE results; therefore, for each statement a graph displaying the relation between students' response to this statement and their average score in both the pre-test and post-test (see Fig. 3) was created. In the case of statements S1, S3 and S4, it is possible to find a correlation between these factors (Pearson correlation coefficient $r \approx -0.94$); statement S2 does not show any strong effect on students' responses. The normalized gain g does not correlate with any of surveyed students' attitudes (with one exception described in the Discussion section below).

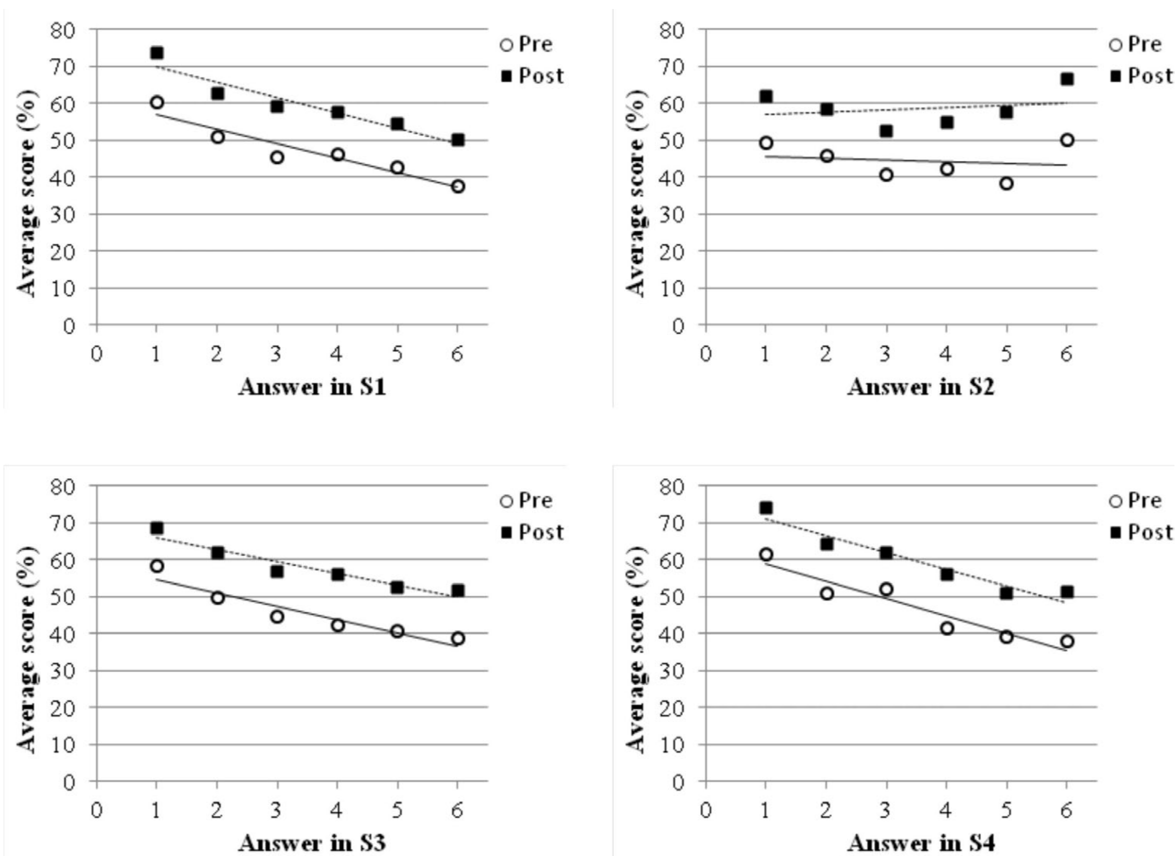

Figure 3: Correlation between responses to S1 to S4 statements and scores in the pre-test and post-test.

Discussion

Thermal Phenomena

The comparison between the pre-test and post-test scores resulting in a normalized gain of 0.23 showed the low effectiveness of traditional instruction, which is fully consistent with the conclusions of many studies dealing with the effectiveness of the traditional teaching approach.

When both the absolute success rates and the normalized gains in particular questions are taken into account, it is obvious that the most problematic part of the whole topic of thermal phenomena lies in the area of phase transitions, or more precisely in the area of associated temperature changes. The strongest misconception identi-

ISSN 1648–3898

fied using CTCE is the belief that when heat is added to the system, the temperature must increase independently of a possible simultaneous phase transition; it doesn't matter if we consider temperature during melting (question 3) or during boiling (questions 5 and 6); in both cases there is a strong tendency to associate heat addition with temperature rise.

While misconceptions described in the previous paragraph rank among the most common ones (e.g. Lewis & Linn, 1994; Yeo & Zadnik, 2001; etc.), the belief that it is not possible to get water at 0 °C (Chu, Treagust, Yeo & Zadnik, 2012) occurs quite rarely in literature. However, almost 44% of Czech students found this claim to be correct in the pre-test (question 11) and what is most paradoxical, in the other question 41% of them (namely 89 students) at the same time chose the answer "the water in the glass was at 0 °C"! This essential contradiction shows a lack of systematic understanding of temperature changes during phase transitions and can indicate the fact that some students chose their responses randomly.

Almost all studies conducted in this field point to students' understanding of the term "cold" as something opposite to "heat"; as another phenomenon occurring in different situations than heat. However, as shown in the Table 4, in the Czech context the importance of such a misconception is insignificant in comparison with the other ones – why this discrepancy? The reason behind it might be the Czech language – the Czech equivalent of the English word "cold" occurs only rarely in everyday speech, which decreases the probability of its infiltration among scientifically correct concepts.

On the other hand, the Czech term for "heat" used in everyday life is from the physics point of view very misleading and can help create a robust misconception, namely that heat is some kind of energy hidden inside matter that can be used to describe any property of a body. CTCE confirmed the strong resilience of this misconception, which remains almost unaffected by the instruction (see Table 5). This may be simply supported by the fact that the widespread and commonly used Czech equivalent of "heat" is used also when speaking about a place with high temperature – for example, the literal translation of the phrase "it is very hot today" would be "it is very heat today". In short, the Czech word for "heat" is used both as a noun and as an adverb. Everyday conversation can therefore lead to perceiving heat more as a state quantity than a process quantity.

A typical example where the Czech language specifics related to heat and cold come into play is question 14 (discussed in detail in the Results of Research section) – after the instruction, many students forsook the concept of cold and chose the response based on the notion of heat as a state quantity; unfortunately, both these responses were incorrect.

A very diverse group is represented by questions dealing with the concept of heat conductivity, i.e. questions 12, 14, 17 and 18. They show a wide range of success rates and normalized gains that may again point to a lack of systematic observations' based conceptual understanding and cause-effect analysis based comprehension – while question 14 had the third worst g, the similarly oriented question 12 showed the second highest g. This notable improvement in question 12 is surprising, because in comparison with other topics, the chapter on heat conductivity is very short (only a few lines) in Czech textbooks; the hypothesis therefore was that the normalized gain related to this topic will be low. Such significant improvement in question 12 might be caused by the fact that students were allowed to use the process of elimination for their decision-making, so they excluded all scientifically incorrect answers and the correct answer was the remaining one; in other words, the correct answering of question 12 in the post-test can reflect a conceptual change in topics unrelated to heat conductivity.

In general, all questions in the area of heat conductivity showed a high discrimination index, i.e., the possibility to distinguish between good and poor students.

The limitation of the study lies in the problem of how to motivate students to do their best while filling out CTCE. Based on the researcher's observations, some students completed the test in an extremely short time (less than 10 minutes) without deeper consideration; however, they did not represent a significant part of the tested population. It can be regarded as a success that there were no students refusing to take part in the research – the ratio of questions that remained unanswered was lower than 0.25%.

Students' Attitudes versus Scores

The responses to four attitudinal questions showed that regarding physics in general, girls are more critical than boys; at the same time, their scores in CTCE were lower, but the normalized gain was the same as in the case of boys. While the majority of respondents find physics to be useful for society, many of them do not see its usefulness for themselves in person. A correlation between students' scores and their attitudes towards physics was found, but there was no such correlation between normalized gain and attitudes. This holds with one exception created by students who marked the S1 and S4 statements with number "1", i.e., those who are going to use physics in their future lives and who really enjoy it (there was a large overlap between these two groups). These probably highly motivated students showed a normalized gain of more than 0.40 and as such do not correspond with the other statistical data.

Conclusions

Between September 2013 and May 2014, almost 500 Czech grammar school students were involved in the study focused on their misconceptions in the field of everyday thermal phenomena. The pre-test–post-test comparison resulting in a normalized gain of 0.23 confirmed the effectiveness of traditional instruction to be low; however, highly motivated students who are going to use physics in their future lives and who really enjoy it achieved an average normalized gain of more than 0.40. Boys' results were slightly better than those of girls and at the same time, their attitudes towards physics seemed to be more positive; despite this, the boys' and girls' average normalized gains did not differ.

The most serious difficulties in understanding were discovered in the field of phase transitions; above all, refusing the fact that temperature does not change during melting, freezing and boiling represents the strongest identified misconception, and one that is very resistant to change. The concept of heat as energy contained in matter is similarly strong, during the instruction even slightly strengthened. On the other hand, the misconception which is often mentioned in literature, i.e.. the existence of both "hot heat" and "cold heat", is in the Czech environment – probably due to language specifics – only minor or quite effectively eliminated during the instruction.

The study also showed that students who enjoy physics, who assume they will need it in the future and who feel its usefulness for themselves achieved better results. However, these factors only influence the absolute success rate, not the normalized gain – apart from the most motivated students mentioned at the beginning of this section. On the other hand, the students declared physics useful for the society as a whole regardless of their scores.

Acknowledgement

This work was supported by The Charles University Grant Agency (GAUK), grant No. 1860214.

References

Alwan, A. A. (2011). Misconception of heat and temperature among physics students. *Procedia - Social and Behavioral Sciences*, *12*, 600-614. doi: 10.1016/j.sbspro.2011.02.074

Ausubel, D. P. (1967). A cognitive structure theory of school learning. In L. Siegel. (Ed.), *Instruction: Some contemporary viewpoints* (pp. 207-257). San Francisco: Chandler.

Baser, M. (2006). Fostering conceptual change by cognitive conflict based instruction on students' understanding of heat and temperature concepts. *Eurasia Journal of Mathematics, Science and Technology Education*, *2* (2), 96-114. Retrieved from http://www.ejmste.com/

Chu, H. E., Treagust, D. F., Yeo, S., & Zadnik, M. (2012). Evaluation of students' understanding of thermal concepts in everyday contexts. *International Journal of Science Education*, *34* (10), 1509-1534. doi:10.1080/09500693.2012.657714.

Clement, J., Brown, D. E., & Zietsman, A. (1989). Not all preconceptions are misconceptions: Finding "anchoring conceptions" for grounding instruction on students' intuitions. *International Journal of Science Education*, *11*, 554-565. doi:10.1080/0950069890110507.

Driver, R. (1983). *The pupil as scientist?* Milton Keynes: Open University Press.

Driver, R., Guesne, E., & Tiberghein, A. (1985). *Children's ideas in science*. Philadelphia: Open University Press.

Erickson, G. L. (1979). Children's conceptions of heat and temperature. *Science Education*, *63* (2), 221-230. doi:10.1002/sce.3730630210.

Fisher, K. M., Williams, K. S., Lineback, J. E. (2011). Osmosis and diffusion conceptual assessment. *CBE Life Sciences Education, 10* (4), 418-429. doi:10.1187/cbe.11-04-0038.

Hake, R. R. (1998). Interactive-engagement vs. traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses. *American Journal of Physics*, *66* (1), 64-74. doi 10.1119/1.18809.

Hammer, D. (1996). More than misconceptions: Multiple perspectives on student knowledge and reasoning, and an appropriate role for education research. *American Journal of Physics*, *64* (10), 1316-1325. doi:10.1119/1.18376.

Harrison, A. G., Grayson, D. J., & Treagust, D. F. (1999). Investigating a grade 11 student's evolving conceptions of heat and temperature. *Journal of Research in Science Teaching*, *36* (1), 55-87.

ISSN 1648–3898

Hestenes, D., Wells, M., & Swackhamer, G. (1992). Force concept inventory. *The Physics Teacher*, *30* (3), 141-158. doi:10.1119/1.2343497.

Hewson, P. W., & Hewson, M. A. G. (1984). The role of conceptual conflict in conceptual change and the design of science instruction. *Instructional Science*, *13* (1), 1-13. doi:10.1007/BF00051837.

Kesidou, S., & Duit, R. (1993). Student's conceptions of the second law of thermodynamics: An interpretive study. *Journal of Research in Science Teaching*, *30* (1), 85-106. doi:10.1002/tea.3660300107.

Lewis, E. L., & Linn, M. C. (1994). Heat energy and temperature concepts of adolescents, adults, and experts: Implications for curricular improvements. *Journal of Research in Science Teaching*, *31* (6), 657-677. doi: 10.1002/tea.3660310607.

Locke, J. (1690). *An essay concerning human understanding*. London: printed by Eliz. Holt, for Thomas Basset.

Luera, G. R., Otto, C. A., & Zitzewitz, P. W. (2005). A conceptual change approach to teaching energy and thermodynamics to pre-service elementary teachers. *Journal of Physics Teacher Education Online, 2* (4), 3-8.

Luera, G. R., Otto, C. A., & Zitzewitz, P. W. (2006). Use of the thermal concept evaluation to focus instruction. *The Physics Teacher*, *44* (3), 162-166. doi: 10.1119/1.2173324.

Maloney, D. P., O'Kuma, T. L., Hieggelke, C. J., & van Heuvelen, A. (2001). Surveying students' conceptual knowledge of electricity and magnetism. *American Journal of Physics, 69* (S1), S12-S23.

McDermott, L. (1993). Guest Comment: How we teach and how students learn–A mismatch? *American Journal of Physics*, *61* (4), 295-298.

McDermott, L. C., & Redish, E. F. (1999). RL–PER1: Resource letter on physics education research. *American Journal of Physics, 67*, 755-767.

Osborne, R., & Freyberg, P. (1985). *Learning in science: The implication of children's science*. Auckland: Heinemann.

Pathare, S., & Pradhan, H. C. (2011). Students' Understanding of Thermal Equilibrium. In Chunawala, S., & Kharatmal, M. (Eds.), *Proceedings of epiSTEME 4 – International Conference to Review Research on Science, Technology and Mathematics Education* (pp. 144-149). India: Macmillan.

Pfundt, H., & Duit, R. (1994). *Students' alternative frameworks and science education* (4th edition). Kiel: University of Kiel.

Piaget, J. (1928). *The child's conceptions of the world*. London: Routledge and Kegan Paul.

Piaget, J. (1952). *The origins of intelligence in children*. New York: International University Press.

Posner, G. J., Strike, K. A., Hewson, P. W., & Gertzog, W. A. (1982). Accommodation of a scientific conception: Towards a theory of conceptual change. *Science Education*, *66* (2), 211-227. doi:10.1002/sce.3730660207

Read, J. R. (2004). *Children's misconpcetions and conceptual change in science education*. Retrieved March 21, 2014, from http://www.asell.org/global/docs/conceptual_change_paper.pdf.

Resnick, L. B. (1983). Mathematics and science learning: A New Conception. *Science*, *220* (4596), 477-478. doi:10.1126/science.220.4596.477.

Sözbilir, M. (2003). A review of selected literature on students' misconceptions of heat and temperature. *Boğaziçi University Journal of Education*, *20* (1), 25-41.

Wenning, C. J. (2008). Dealing more effectively with alternative conceptions in science. *Journal of Physics Teacher Education Online*, *5* (1), 11-19.

Wiser, M., & Amin, T. (2001). "Is heat hot?" Inducing conceptual change by integrating everyday and scientific perspectives on thermal phenomena. *Learning and Instruction*, *11* (4-5), 331-355. doi:10.1016/S0959-4752(00)00036-0.

Yeo, S., & Zadnik, M. (2001). Introductory thermal concept evaluation: Assessing Students' Understanding. *The Physics Teacher*, *39*, 495-504.

Appendix: The TCE – questions involved in the Czech version (CTCE)

1. What is the most likely temperature of ice cubes stored in a refrigerator's freezer compartment? a) –10 °C b) 0 °C c) 5 °C d) It depends on the size of the ice cubes.	**2.** Jirka takes six ice cubes from the freezer and puts four of them into a glass of water. He leaves two on the countertop. He stirs and stirs until the ice cubes are much smaller and have stopped melting. What is the most likely temperature of the water at this stage? a) –10 °C b) 0 °C c) 5 °C d) 10 °C
3. The ice cubes Jirka left on the counter have almost melted and are lying in a puddle of water. What is the most likely temperature of these smaller ice cubes? a) –10 °C b) 0 °C c) 5 °C d) 10 °C	**4.** On the stove is a kettle full of water. The water has started to boil rapidly. The most likely temperature of the water is about: a) 88 °C b) 98 °C c) 110 °C d) 120 °C

5. Five minutes later, the water in the kettle is still boiling. The most likely temperature of the water now is about:
a) 88 °C
b) 98 °C
c) 110 °C
d) 120 °C

6. What do you think is the temperature of the steam above the boiling water in the kettle?
a) 88°C
b) 98 °C
c) 110 °C
d) 120 °C

7. Ivana takes two cups of water at 40 °C and mixes them with one cup of water at 10 °C. What is the most likely temperature of the mixture?
a) 20 °C
b) 25 °C
c) 30 °C
d) 50 °C

8. Petr believes he must use boiling water to make a cup of tea. He tells his friends: "I couldn't make tea if I was camping on a high mountain because water doesn't boil at high altitudes."
a) Martin says: "Yes it does, but the boiling water is just not as hot as it is here."
b) Pavel says: "That's not true. Water always boils at the same temperature."
c) Jakub says: "The boiling point of the water decreases, but the water itself is still at 100 degrees."
d) Tomáš says: "I agree with Petr. The water never gets to its boiling point."
Who do you agree with?

9. Petra takes a can of cola and a plastic bottle of cola from the refrigerator, where they have been overnight. She quickly puts a thermometer in the cola in the can. The temperature is 7 °C. What are the most likely temperatures of the plastic bottle and cola it holds?
a) They are both less than 7 °C.
b) They are both equal to 7 °C.
c) They are both greater than 7 °C.
d) The cola is at 7 °C but the bottle is greater than 7 °C.
e) It depends on the amount of cola and/or the size of the bottle.

10. A few minutes later, Petra picks up the cola can and then tells everyone that the countertop underneath it feels colder than the rest of the counter.
a) Tereza says: "The cold has been transferred from the cola to the counter."
b) Jitka says: "There is no energy left in the counter beneath the can."
c) Katka says: "Some heat has been transferred from the counter to the cola."
d) Eliška says: "The can causes heat beneath the can to move away through the countertop."
Whose explanation do you think is best?

11. Roman asks one group of friends: "If I put 100 grams of ice at 0 °C and 100 grams of water at 0 °C into a freezer, which one will eventually lose the greatest amount of heat?
a) Honza says: "The 100 grams of ice."
b) Marek says: "The 100 grams of water."
c) Milan says: "Neither because they both contain the same amount of heat."
d) Patrik says: "There's no answer, because ice doesn't contain any heat."
e) Aleš says: "There's no answer, because you can't get water at 0 °C."
Which of his friends do you most agree with?

12. Jana takes a metal ruler and a wooden ruler from her pencil case. She announces that the metal one feels colder than the wooden one. What is your preferred explanation?
a) Metal conducts energy away from her hand more rapidly than wood.
b) Wood is a naturally warmer substance than metal.
c) The wooden ruler contains more heat than the metal ruler.
d) Metals are better heat radiators than wood.
e) Cold flows more readily from a metal.

13. Dita took two glass bottles containing water at 20 °C and wrapped them in washcloths. One of the washcloths was wet and the other was dry. Twenty minutes later, she measured the water temperature in each. The water in the bottle with the wet washcloth was 18 °C, the water in the bottle with the dry washcloth was 22 °C. The most likely room temperature during this experiment was:
a) 26 °C
b) 21 °C
c) 20 °C
d) 18 °C

14. Pavel simultaneously picks up two cartons of chocolate milk, a cold one from the refrigerator and a warm one that has been sitting on the countertop for some time. Why do you think the carton from the refrigerator feels colder than the one from the countertop? Compared with the warm carton, the cold carton —
a) contains more cold.
b) contains less heat.
c) is a poorer heat conductor.
d) conducts heat more rapidly from Pavel's hand.
e) conducts cold more rapidly to Pavel's hand.

15. Bára reckons her mother cooks soup in a pressure cooker because it cooks faster than in a normal saucepan but she doesn't know why.
a) Kristýna says: "It's because the pressure causes water to boil above 100°C."
b) Eva says: "It's because the high pressure generates extra heat."
c) Karolína says: "It's because the steam is at a higher temperature than the boiling soup."
d) Andrea says: "It's because pressure cookers spread the heat more evenly through the food."
Which person do you most agree with?

16. When Ondra uses a bicycle pump to pump up his bike tires, he notices that the pump becomes quite hot. Which explanation below seems to be the best one?
a) Energy has been transferred to the pump.
b) Temperature has been transferred to the pump.
c) Heat flows from his hands to the pump.
d) The metal in the pump causes the temperature to rise.

ISSN 1648–3898

17. Why do we wear sweaters in cold weather?
a) To keep cold out.
b) To generate heat.
c) To reduce heat loss.
d) All three of the above reasons are correct.

18. Filip takes some Popsicles from the freezer, where he had placed them the day before, and tells everyone that the wooden sticks are at a higher temperature than the ice part. Which person do you most agree with?
a) Radek says: "You're right because the wooden sticks don't get as cold as ice does."
b) Luboš says: "You're right because ice contains more cold than wood does."
c) Viktor says: "You're wrong, they only feel different because the sticks contain more heat."
d) Štěpán says: "I think they are at the same temperature because they are together."

19. Lenka is describing a TV segment she saw the night before: "I saw physicists make super-conductor magnets, which were at a temperature of –260 °C."
a) Radim doubts this: "You must have made a mistake. You can't have a temperature as low as that."
b) Dominik disagrees: "Yes you can. There's no limit on the lowest temperature."
c) Matyáš believes he is right: "I think the magnet was near the lowest temperature possible."
d) Tonda is not sure: "I think super-conductors are good heat conductors so you can't cool them to such a low temperature."
Who do you think is right?

Received: *February 19, 2015* Accepted: *March 26, 2015*

Petr Kacovsky Master of Science, Ph.D. Student, Charles University in Prague, Department of Physics Education, Faculty of Mathematics and Physics, V Holesovickach 2, Prague 180 00, Czech Republic.
E-mail: petr.kacovsky@mff.cuni.cz
Website: http://www.mff.cuni.cz/fakulta/struktura/lide/6932.htm