DO MISLEADING THERMAL SENSATIONS UNDERLIE SOME HEAT AND COLD MISCONCEPTIONS?

Ivan Ezquerra-Romano[1]*, Federico Agen*[2] *and Angel Ezquerra*[2]
[1]Institute of Cognitive Neuroscience, University College London (UCL), London, UK,
[2]Science, Social Science and Mathematics Education, Universidad Complutense de Madrid, Spain

Alternative conceptions are ideas found universally in people, regardless of their age, education, sex, race and religion. This suggests that there exists an underlying reason common to all human beings. Recently, it has been proposed that misconceptions might arise from the ambiguity in the perception of external stimuli (physical variables). The aim of this study was to explore whether misconceptions on heat and "cold" are based on thermal sensations. We prepared three objects with different thermal conductivity and we kept them at constant temperatures. Then, 160 students (12-15 years old) were presented with the objects along with a set of questions. Although the objects were at the same temperature, students reported different sensations and estimated temperatures. When students were asked to explain why they felt those sensations, we identified common misconceptions. The ambiguity of thermosensation and the identified common misconceptions suggest that misleading sensations contribute to the development of well-known misconceptions on heat and temperature. Finally, revealing the real temperature of the objects to students resulted in a tendency to reject their first explanation and to seek for an alternative one. Understanding how concepts are grounded on our perception will help developing teaching strategies that tackle these misconceptions.

Keywords: Misconceptions, Learning and Neuroscience, Conceptual Understanding

INTRODUCTION AND THEORETICAL FRAMEWORK

Feeling temperature is a matter of life or death. Humans show a broad range of highly elaborate responses to temperature changes such as wearing clothes, developing air conditioning systems or switching the heating on. These complex responses seem to be based on our mental representations –or concepts- of heat, "cold", temperature, etc.

It has been observed that concepts are developed in an ordered and universal sequence. This process was called conceptual trajectory by Driver (1989). The ideas found at each step of the conceptual trajectory are usually called alternative conceptions or misconceptions (Driver and Easley, 1978; Abimbola, 1988). These alternative conceptions are very common, and they transcend age, education, sex, and culture (Abrahams et al., 2015). They are also very persistent and resistant to change and to extinction (Chiappetta & Koballa, 2006). The universality and persistency of alternative conceptions suggest that there exists an underlying reason common to all human beings. Some researchers have suggested that the way our senses work influence the development of spontaneous ideas (Wenning, 2008). Recently, it has been proposed that misconceptions might arise from perceptual ambiguity in the perception of external stimuli (physical variables) (Ezquerra-Romano & Ezquerra, 2017; Kubricht, Holyoak & Lu, 2017; Ezquerra & Ezquerra-Romano, 2018).

The aims of this study were:

- To explore how we describe the thermal state of objects based on our thermal perception
- To analyse statements about the reasons for the given descriptions based on perceptual ambiguity
- To discuss the statements in the context of thermosensation

Firstly, we asked students to rate the sensations and the temperature of different objects. Then, students had to interpret their sensations. After this, we revealed the real temperature of the objects to students and asked students to interpret their sensations again.

RESEARCH METHOD AND DESIGN

We prepared three objects with different thermal conductivities (TC): polyethylene foam, K = 0.03-0.04 W/m·K (low TC); brick, K = 1.31 W/m·K (medium TC) and aluminium, K = 205 W/m·K (high TC). There were four conditions: 10.9 ºC, 23.0 ºC, 33.6 ºC, and 38.1 ºC. In each condition, all objects were kept at the same temperature. The experiment was conducted in 4 different high schools in Madrid (Spain). In total 160 students (12-15 years old) were presented with the objects alongside the following questions (36 students at 10.8 ºC; 39 students at 23.0 ºC, 42 students at 33.6 ºC, 43 students at 38.1 ºC):

- Question 1: What did you feel when you touched each object?
- Question 2: At what temperature do you think each object is?
- Question 3: Explain with your own words why you felt this sensation when you touched the object.
- Question 4: Once the temperature of the objects is known, explain why you think this is so.

Question 1 and 2 measured the perceptual quality and quantity of the thermal percepts. Question 3 aimed to trigger interpretation of the thermal sensations. After Question 3 was answered, students were asked to check the temperature of each object with an Infrared thermometer (model: Fisherbrand™ Traceable™ Infrared Dual Lasers Thermometer w/Type-K Probe). Then, the students replied Question 4, which goal was to again prompt interpretation of the sensations.

In our analysis, we did not control for group, age or school. We pooled all the values by conditions. We are interested in studying universal tendencies about how misleading sensations contribute to the development of well-known misconceptions on heat and temperature.

RESULTS

To analyse the answers to Question 1, we identified the units of information (words, expressions or sentences) used by students to describe what they felt. Based on Green, Roman, Schoen & Collins (2008), we grouped them in seven categories (icy, cold, cool, in-between, warm, hot, burning, and nothing). Table 1 shows students' responses when the objects were at 10.8 ºC and 38.1 ºC.

Table 1. Frequency and percentage of the units of information found in answers to question 1 to describe what students felt. The units of information were grouped in 7 categories (icy, cold, cool, in-between, warm, hot, burning, and nothing). Data is from conditions in which objects were at 10.8 ºC and 38.1 ºC.

	10.8 ºC						38.1 ºC					
	Foam Low TC		Brick Medium TC		Aluminium High TC		Foam Low TC		Brick Medium TC		Aluminium High TC	
Icy	0	0.0 %	6	16.7 %	27	75.0 %	0	0.0 %	0	0.0 %	0	0.0 %
Cold	2	5.6 %	13	36.1 %	7	19.4 %	2	4.7 %	5	11.6 %	0	0.0 %
Cool	4	11.1 %	12	33.3 %	2	5.6 %	2	4.7 %	2	4.7 %	0	0.0 %
In-between	11	30.6 %	3	8.3 %	0	0.0 %	9	20.9 %	8	18.6 %	1	2.3 %
Warm	17	47.2 %	2	5.6 %	0	0.0 %	20	46.5 %	14	32.6 %	0	0.0 %
Hot	2	5.6 %	0	0.0 %	0	0.0 %	10	23.3 %	12	27.9 %	15	34.9 %
Burning	0	0.0 %	0	0.0 %	0	0.0 %	0	0.0 %	1	2.3 %	27	62.8 %
NR	0	0.0 %	0	0.0 %	0	0.0 %	0	0.0 %	1	2.3 %	0	0.0 %
Total	36	100	36	100	36	100	43	100	43	100	43	100

We found that the distribution of responses was different for each object at all temperatures (Table 1). Specifically, most units of information found when describing the sensation elicited by touching foam fell in 'In-between' and 'Warm'. In the case of brick, the frequency of units of information varied across conditions. In the conditions at 10.8ºC and 23.0ºC, most units of information fell in the categories 'Cold' and 'Cool'. In the conditions at 33.6ºC and 38.1ºC, most units of information fell in the categories 'In-between', 'Warm' and 'Hot'. In the case of aluminum, we found a stronger deviation of the units of information from central categories. In the conditions at 10.8ºC and 23.0ºC, most units of information fell in the categories 'Icy' and 'Cold'. In the conditions at 33.6ºC and 38.1ºC, most units of information fell in the categories 'Hot' and 'Burning'.

Importantly, responses in all conditions (object and temperature) are distributed across categories (Table 1). Namely, sensations did not consistently fall within one category.

Overall, these results indicate that student's thermal perception depends on the temperature of the objects, and, given a constant temperature, perception depends on the TC of the materials. They also show a disagreement in the categorisation of sensations. Individuals categorise sensations elicited by objects differently. This could result in miscommunications, which could be problematic in educational settings.

Although objects were at the same temperature for each condition, the answers to Question 2 showed that students assigned different temperatures to each object. Figure 1 shows the distribution for the frequencies of temperatures reported by students when the objects were at 23.0 ºC. Table 2 shows the data for all temperatures.

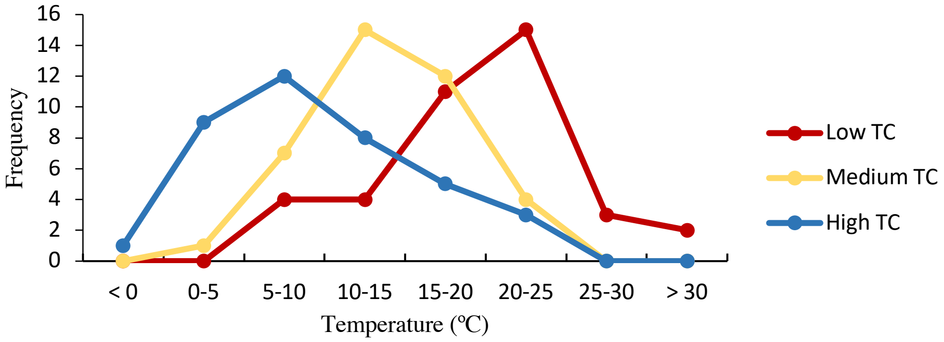

Figure 1. Frequency of temperatures reported by students when objects were at 23.0 ºC. Mean average: low TC, 18.3 ºC: medium TC, 12.4 ºC; high TC, 8.2 ºC.

As shown in Table 2, the means of the object temperature estimation within each condition differed. At each condition, pair-wise paired t-tests revealed significant differences ($p < 0.05$) within conditions except for foam vs brick at 33.6ºC and foam vs brick at 38.1ºC.

Table 2. Mean, standard deviation (S.D.) and kurtosis from temperature estimations in Question 2.

Condition	Statistical parameters	Foam Low TC	Brick Medium TC	Aluminium High TC
10.8 ºC	Mean	13.9	7.5	1.7
	S.D.	9.1707	10.3865	9.8556
	Kurtosis	0.2913	4.5644	1.3306
23.0 ºC	Mean	18.3	12.4	8.2
	S.D.	6.6598	4.9460	6.7310
	Kurtosis	-0.2529	-0.1279	-0.3125
33.6 ºC	Mean	19.9	22.8	41.6
	S.D.	11.1052	11.5876	18.3204
	Kurtosis	1.1404	-0.0617	0.7115
38.1 ºC	Mean	19.8	19.6	40.9
	S.D.	22.4555	17.0863	31.4946
	Kurtosis	28.7328	11.2502	16.2788

These results indicate that students were not able to make a correct estimate of the temperature of the objects with their thermal sensation. Consistent with the previous quesiton, these results suggest that object temperature estimation depends on the temperature of the object and its thermal conductivity. On the one hand, the estimated temperature is related to the temperature of the object. On the other hand, the estimated temperature varies as a function of the thermal conductivity for a constant temperature. The estimated temperature varies more when touching a material with high thermal conductivity as opposed to when a material with low thermal conductivity is touched. This suggests that the effect of thermal conductivity on the estimated temperature is lower for materials with low thermal conductivity.

Moreover, the standard deviation and kurtosis differs within and across conditions. At 38.1°C, the kurtosis is positive and high, which indicates a sharp peak compared to a normal distribution. At this temperature, the responses gravitate closer to the mean (positive kurtosis). At 33.6°C, the kurtosis was very close to cero with negative and positive values for different objects. At 23.0°C, the responses were more spread (negative kurtosis and very close to cero). Therefore, at 33.6°C and 23°C, the responses are more spread than at 38.1°C. At 10.8°C, we observed positive values of the kurtosis, but not as high as those for 38.1°C. Importantly, the mean temperature of the skin is 32-33°C (Rajek et al., 2000). These results suggest that object temperature estimations are less spread at extreme temperatures than at less extreme temperatures.

To analyse the answers to Question 3 and 4, we identified, collated and classified the units of information (words, expressions or sentences) used by students to explain what and why they felt. Question 4 was formulated after students revealed the real temperature of the objects.

Consistent with the literature, students based their explanations on well-known alternative conceptions. Some examples were: “the heat (do not) travels to the fingers”, “Polyethylene is warmer because it keeps internal heat” or “metals are cold materials”. These statements reveal two kind of misconceptions. Firstly, these explanations assume that heat is a fluid that moves from object to object (caloric theory). Secondly, they also show the misconception that materials are naturally hot or cold (Brook et al., 1985), or attractors of hotness/coldness (Kesidou and Duit, 1993). Therefore, based on the literature, we grouped the units of information in 4 categories: material has heat/cold (mhhc); the materials are different (md); we perceive differently (pd); caloric theory (ct).

Figure 3 shows the frequency for each category. The analysis revealed that many students’ explanations contained units of information belonging to more than one category. We noticed that in many explanations the units of information identified were contradictory. Therefore, the total sum is greater than the number of students and it differs between Question 3 and 4. In our design, we did not expect this. Therefore, we could not conduct a properly designed statistical analysis.

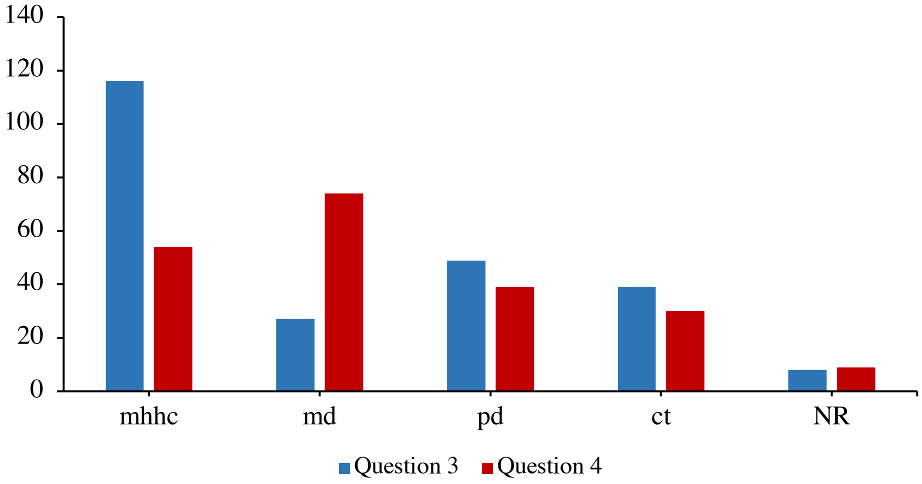

Figure 2. Frequency of the units of information found in the explanations given to Question 3 and 4.

However, we observed a trend in the frequency of units of information in Question 3 and 4 (Figure 2). It seems that knowing the real value of the temperature made students to change their explanations. In Question 3, most units of information fell in the category 'Material has heat/cold', whereas in Question 4 most units of information were classified in the group 'Materials are different'.

DISCUSSION AND CONCLUSIONS

In this study, we presented three objects with different thermal conductivity at constant temperatures to students in high school (12-15 years old). Although objects were at the same temperature in each condition (10.9 ºC, 23.0 ºC, 33.6 ºC, and 38.1 ºC), we found differences in the categorisation of sensations (Question 1; Table 1) as well as in the estimation of objects' temperatures (Question 2; Table 2 & Figure 1). Furthermore, we found common misconceptions when students were asked to explain the reasons why they perceived those sensations (Question 3; Figure 2). Finally, when the real temperature of the objects was revealed to students, we observed a tendency to reject their first explanation and to seek for an alternative one (Question 4).

The results obtained in Question 1 and 2 are coherent (Table 1 & 2 and Figure 1). They indicate that there is not common agreement when labelling the sensation. This is supported by the distribution of the frequencies in Table 1 and by the pattern of the responses in Table 2 and Figure 2. Additionally, these results also show that thermal perception depends on material's thermal conductivity and their temperature. This is consistent with previous literature that showed how subjects can discriminate between materials based on thermal cues (Ho & Jones, 2006). Our results show that thermal perception is ambiguous (Ezquerra-Romano & Ezquerra, 2017; Kubricht, Holyoak & Lu, 2017). They support the theory that perceptual ambiguity of physical variables influences the development of alternative conceptions (Wenning, 2008; Ezquerra & Ezquerra-Romano, 2018).

In the context of teaching, this observation has important consequences. It is challenging to find an agreement when labelling sensations, given that each individual will categorise the sensation differently. Consequently, miscommunications are likely to occur. When explaining concepts related to heat and temperature, pupils might get lost in the reasoning when, for instance, the teacher uses real-life examples. Each individual will picture a different sensation, which might lead to inaccurate understandings.

Furthermore, our results in Question 2 show that many students are very far from the real temperature of objects when they were asked to estimate their temperature. This observation reveals a problem in the context of education. Students find it difficult to estimate object's temperature, which seems to have an internal origin (perception). Moreover, their learning through daily-life experiences (external) has not provided them with the right tools to estimate objects' temperature. We suggest two solutions to tackle this problem. Firstly, students should be aware of the limitation of their thermosensation. To accomplish this, content about the workings of our thermosensory system should be included in lessons of thermodynamics (Ezquerra and Ezquerra-Romano, 2019). Secondly, students in early stages of the school curriculum should carry out activities in which they estimate and measure the temperature of objects in their familiar environments (e.g. At what temperature are the following items? Soup, shower, soft drink with ice).

Moreover, the explanations given in Question 3 and 4 were consistent with the sensations and temperatures reported in Question 1 and 2. Overall, analysis of the identified misconceptions showed that students based their explanations on their reported sensations. Interestingly, even when their perception was challenged with the real temperature (Question 4), their explanations kept relying on the perceived sensations. However, we found a trend to find alternative explanations after the real temperature of the object was revealed. This change does not result from a conceptual change. Nevertheless, this activity (to experience the thermal sensation of different objects and measure its temperature) triggered an immediate intention to change their explanation. There are two stages in this process. Firstly, they rejected their first explanation. Secondly, they sought for an alternative explanation. This activity catalysed a rupture of the cognitive equilibirum (Pritchard & Woollard, 2010).

Our results are coherent with the way that our thermosensory system works (Ezquerra-Romano & Ezquerra, 2017). We do not have a unique temperature detection mechanism (a thermometer), but a family of thermoTRPs that work at different ranges (Schepers & Ringkamp, 2010). Furthermore, thermal information is transmitted separately through two main channels in the nervous system, which contributes to the conceptual creation of two ranges: hot and "cold" (Craig, 2003; Ezquerra & Ezquerra-Romano, 2018).

It seems that the structure and arrangement of our thermosensory system shapes and constrains the creation of the concepts of heat and "cold". Understanding how concepts are shaped by our perception will help developing teaching strategies that directly tackle ingrained misconceptions.

ACKNOWLEDGEMENT

This work has been funded by Project RTI2018-094303-A-I00 of the Ministry of Economy and Competitiveness, Spain, the State R & D & I Program Oriented to the Challenges of the Society, State Plan for Scientific Research and Technical and Innovation 2018.

REFERENCES

Abimbola, I. O. (1988). The problem of terminology in the study of student conceptions in science. Science Education, 72(2), 175-184.

Abrahams, I., Homer, M., Sharpe, R., & Zhou, M. (2015). A comparative cross-cultural study of the prevalence and nature of misconceptions in physics amongst English and Chinese undergraduate students. Research in Science & Technological Education, 33(1), 111-130.

Brook, A., Briggs, H., Bell, B. and Driver, R. (1985). Secondary students' ideas about heat: Workshop pack, children's learning in science project. Leeds, UK, University of Leeds, Centre for Studies in Science and Mathematics Education.

Chiappetta, E. L., & Koballa, Jr., T. R. (2006). Science Instruction in the Middle and Secondary Schools. Upper Saddle River, NJ: Pearson/Merrill Prentice Hall.

Craig, A. (2003). A new view of pain as a homeostatic emotion. Trends in Neurosciences, 26(6), 303-307.

Driver, R. (1989). Students' conceptions and the learning of science. International journal of science education, 11(5), 481-490.

Driver, R., & Easley, J. (1978). Pupils and paradigms: A review of literature related to concept development in adolescent science students. Studies in Science Education, 5, 61–84.

Ezquerra, A. and Ezquerra-Romano, I. (2018). From Thermosensation to the Concepts of Heat and Temperature: A Possible Neuroscientific Component. Eurasia Journal of Mathematics, Science and Technology Education, 14(12).

Ezquerra, A. and Ezquerra-Romano, I. (2019). Using neuroscience evidence to train pre-service physics teachers on the concepts of heat and cold. Journal of Physics: Conference Series, Volume 1287 (1).

Ezquerra-Romano, I., & Ezquerra, A. (2017). Highway to thermosensation: a traced review, from the proteins to the brain. Reviews in the Neurosciences, 28(1), 45–57.

Green, B. G., Roman, C., Schoen, K., & Collins, H. (2008). Nociceptive sensations evoked from 'spots' in the skin by mild cooling and heating. PAIN®, 135(1-2), 196-208.

Ho, H. N., & Jones, L. A. (2006). Contribution of thermal cues to material discrimination and localization. Perception & Psychophysics, 68(1), 118-128.

Kesidou, S. y Duit, R. (1993). Students' conceptions of the second law of thermodynamics - An interpretive study. Journal of Research in Science Teaching, 30, 85-106.

Pritchard, A. & Woollard, J. (2010). Psychology for the classroom: Constructivism and social learning. New York: Routledge.

Rajek, A., Grief, R., Sessler, D. I., Baumgardner, J., Laciny, S., & Bastanmehr, H. (2000). Core cooling by central venous infusion of icecold (4 degrees Celcius or 20 degrees Celcius) fluid: isolation of core and peripheral thermal compartments. Anaesthesiology, 93(3), 629-637.

Schepers, R. J., & Ringkamp, M. (2010). Thermoreceptors and thermosensitive afferents. Neuroscience & Biobehavioral Reviews, 34(2), 177-184.