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The Proceedings of ESERA 2021 is an electronic publication for revised and extended papers presented at the ESERA 2021 conference organised by the University of Minho, Portugal, from 30 August to 3 September 2021. All papers in the e-Proceedings correspond to communications submitted and accepted for the ESERA 2021 conference. All proposals to the conference went through a double-blind review process by two or three reviewers before being accepted to the conference. A total of 739 proposals (out of which 33 were symposia) were presented at the conference, and 158 papers are included in the ESERA e-Proceedings, 5 of them from symposia.

The authors were asked to produce updated versions of their papers and consider the discussion that took place after the presentation and the suggestions received from other participants at the conference. The e-Proceedings presents a comprehensive overview of ongoing studies in Science Education Research in Europe and beyond. This book represents the current interests and areas of emphasis in the ESERA community at the end of 2021.

The e-Proceedings book contains seventeen Parts representing papers presented across 17 strands at the ESERA 2021 conference. The strand chairs for ESERA 2021 co-edited the corresponding Part for each strand 1 to 17. All formats of presentation (single oral, interactive poster, demonstration/workshop and symposium) used during the conference were eligible to be submitted to the e-Proceedings.

The co-editors reviewed the updated versions of the papers submitted after the conference at the end of 2021. ESERA, the editors and co-editors do not necessarily endorse or share the ideas and views presented in or implied by the papers included in this book.

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WITHIN THE PROCEEDINGS:

Part 1 / Strand 1

Learning Science: Conceptual Understanding

Co-editors: *Ana Sofia Afonso & Massimiliano Malgieri*

Part 1. Learning Science: Conceptual Understanding

Theories models, and empirical results on conceptual understanding, conceptual change and development of competences; methodology for investigating students' processes of concept formation and concept use; strategies to promote conceptual development.

MEASURING OUR OWN TEMPERATURE SCALE(S). FROM THERMAL SENSATIONS TO THERMAL CONCEPTS

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Research has suggested that some characteristics of misconceptions are explained by the way we perceive the world. In this study, we investigated the relationship between thermal sensations, temperature estimations and the real temperature scale. To perform this experiment, we developed a novel device, which produces a thermal gradient. Participants had to slide one index finger along the thermal gradient. They were asked to indicate where they detected a change of sensation and to estimate the temperature. The temperature at which participants detected a change of sensation was consistent, whereas the spread of estimated temperatures was significantly higher. This suggests the existence of a common perceptual-qualitative scale and an agreement in how it is reported, but a lack of an appropriate representation of the temperature variable. The presence of this mismatch poses a challenge for teaching and learning concepts about temperature. We propose that this mismatch is a product of differences in the learning process. In this sense, teaching staff should understand the neuropsychological basis of misconceptions to tackle the learning difficulties of their students more effectively.

Keywords: Conceptual Understanding, Misconceptions, Learning and Neuroscience

INTRODUCTION AND THEORETICAL FRAMEWORK

Misconceptions are universal. They are found in people around the world regardless their age, education, gender and cultural background (Abrahams et al., 2015). Moreover, misconceptions seem very persistent and resistant to change (Chiappetta & Koballa, 2014). These characteristics suggest that there is a common basis. In this sense, research has proposed that some of their characteristics can be explained by the way our nervous system works (Vosniadou, 1994).

The fields of science education and psychology of learning have categorised misconceptions about the concepts of temperature and heat (Driver, 1989; Piaget, 2007). People conceptualise temperature as a discontinuous scale, which is divided in two by the great concepts of hot and cold and has a blurry neutral zone (Albert, 1978; Clough & Driver, 1985; Erickson, 1979; Tiberghien, 1985).

Temperature perception is vital for survival. Biological organisms need to monitor the temperature of their tissues for optimal functioning of metabolic processes. Beyond physiological reactions such as sweating and shivering, humans show a wide range of complex behaviours such as making fire or developing air conditioning systems. These behaviours are the expression of cognitive processes that necessarily imply the existence of a representation or conceptualisation of the temperature magnitude and its corresponding scale (Ezquerra & Ezquerra-Romano, 2018).

Thermal perception is supported by the thermosensory system (Figure 1). In the skin, temperature changes are transformed into neural activity by receptors which are called thermoTRPs. Interestingly, humans have a family of thermoTRPs that allow us to feel temperatures between 17 ºC and 30 ºC (innocuous cold range) and between 36 ºC and 43 ºC (innocuous hot range) (Ezquerra-Romano & Ezquerra, 2017; Patapoutian et al., 2003). However, each thermoTRP is only sensitive to a subrange within either the cold or warm ranges. Moreover, the response of thermoTRPs to thermal stimuli is not linear within their subrange.

ThermoTRPs are embedded in the membrane of thermosensitive neurons. Many of these neurons only express a type of thermoTRP. This means that they are only sensitive to a thermal subrange. Thus, cold and warm signals are transmitted separately. This separation is maintained in the spinal cord and these signals also arrive separately to different parts of the brain (Ezquerra-Romano & Ezquerra, 2017). Finally, thermal information is also integrated in the brain and the perception of temperature emerges from the synergistic interactions between different brain areas.

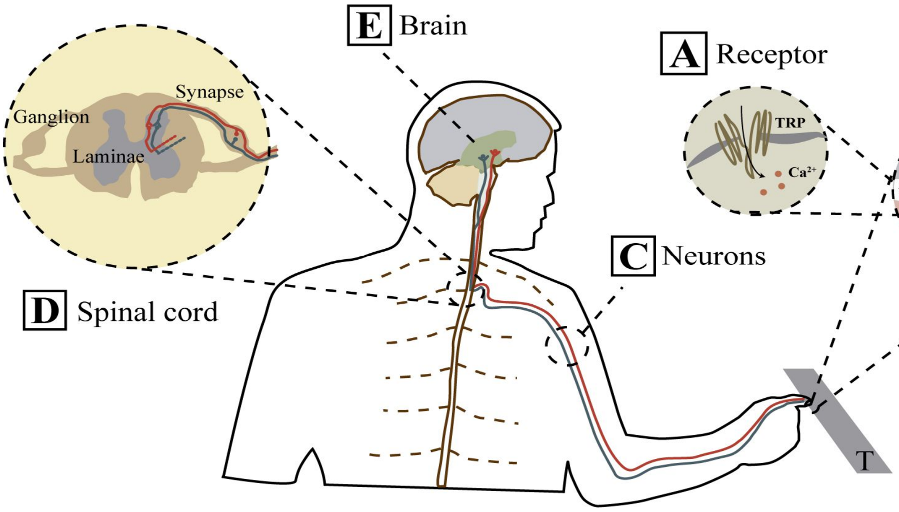

Figure 1. Schematic diagram of the neurophysiology of the thermosensory system. [A] Receptors (TRPs) sensitive to temperature changes. They are embedded in the membrane of neurons. As a result, these neurons become sensitive to temperature changes too. [B] The endings of thermosensitive neurons are located in the dermis. They are exposed to heat flux between tissues and objects. [C] Neurons sensitive to innocuous cooling (blue) and warming (red) carry thermal signals separately to the spinal cord. [D] The separation between cold and warm signals is maintained in the spinal cord. [E] Warm and cold sensations are encoded in different parts of the brain. Adapted from Ezquerra-Romano & Ezquerra (2017).

In summary, thermoTRPs have large, overlapping and non-linear response subranges within the whole thermal range. These receptors are expressed in different fibres, and this separation is maintained along the thermosensory pathway, but thermal information is integrated only in particular brain areas. Additionally, thermosensation not only depends on the temperature of objects, but other factors also contribute to the experience of temperature such as the materials' conductivity (Ezquerra-Romano et al., 2019). Thus, our thermosensory system does not work like a thermometer. Our thermal sensations are not represented like the measurement of a precise sensor which linearly measures a unique variable.

From a declarative perspective, we categorise thermal experiences in two wide ranges, cold and hot, which can be further subdivided with different terms (e.g. cool) and adverbs (e.g. very)

(Green et al., 2008). However, from a conceptual perspective (in Physics), temperature is defined as a quantity on a numeric continuous scale with 0 K (- 273.15º C) as a starting point. The concepts of hot and cold are straightforward, but subdivisions are blurry, and the sensations assigned to these categories do not seem to have a clear representation on the physical scale. All in all, there seems to be a mismatch between the way we talk about temperature (declarative perspective) and the way physicists think about temperature (conceptual perspective).

In the science education context, the integration of neuroscience and science education could allow us to study teaching and learning processes from a biological point of view. This knowledge would help science teachers and traineers dealing with students' misconceptions and cognitive processes more effectively (Ezquerra-Romano et al., 2019).

RESEARCH METHOD AND DESIGN

In this study, we investigated the mismatch between our thermosensory scale, which is dictated by our neurobiology, and the temperature scale, which is defined in Physics. We obtained the points at which people detected a change in thermal sensation and the numerical estimation of the temperature at these points. We compared these measurements between each other.

To deliver thermal stimuli to participants, we developed a novel device called *Termosensimetro* (Figure 2) (Spanish Patent No. 202030815, 2020). The device creates a continuous thermal gradient from 10 ºC to 50 ºC along a metal bar using Peltier modules. To track the position of the participant's fingers, there is a tactile sensor parallel to the metal bar. The temperature on the metal bar and the position of the finger on the tactile sensor are mapped with a one-to-one relationship. The device is equipped with different control elements which are driven by Arduino. Custom-written code was used to coordinate the electronic components and collect the data.

In each trial, participants had to slide one index finger along the metal bar. They were asked to indicate where they perceived a change of thermal sensation by touching the tactile sensor. After touching the tactile sensor, participants were asked to label the sensation and estimate the temperature.

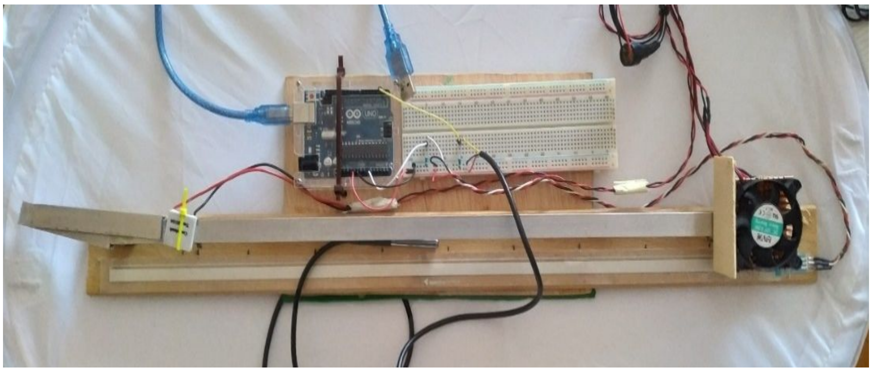

Figure 2. ***Termosensimetro*** **prototype. Thermal stimulator that produces a thermal gradient along the grey metal bar. The thermal gradient is produced by Peltier modules at both ends of the grey metal bar. The tactile sensor is the white band below the metal bar.**

To label the thermal sensations, the Labelled Magnitude Scale (LMS) was adapted from Green et al. (2008). The thermal range was divided into an ordinal scale: Painfully Cold (PC), Very

Cold (VC), Cold (C), Neutral (N), Hot (H), Very Hot (VH), and Painfully Hot (PH). The point at which participants indicated a change of thermal sensation was used to determine the *'perceptual change point'* (e.g., from VC to C). After labelling the sensation, subjects were asked to estimate the temperature. This numerical value (degrees Celsius, ºC) was called *'estimated numerical value'*. Both the labelled sensations (LMS) and the *'estimated numerical value'* (Celsius) were noted down by the researcher during the experiment. The 'perceptual change point' was automatically recorded by *Termosensimetro*.

The pressure between the skin and objects modulates thermal sensations. When the pressure is low, heat flux is inefficient or partially stopped. On the other hand, a high pressure would result in the mechanical sensations confounding the temperature ones. Therefore, we established a standard force of 12 g which participants learnt to apply with a pocket weight scale before each trial (Dyck et al., 1978). Moreover, to minimise neural fatigue, a 5-second waiting period was introduced between each trial.

All experiments were carried out individually, in a controlled room with a room air temperature of 25 ºC and a relative humidity of 30–40 % to keep thermal conditions constant and ensure participants' comfort.

When initialising the device, we had to perform some checks to ensure the device was performing correctly. Firstly, we measured the temperature of the metal at different points until thermal stability was reached. The warmup time was approximately 20 minutes. Secondly, we checked that our thermal gradient was approximately linear, so we could deploy the one-to-one mapping between the temperature on the metal bar and the position of the finger on the tactile sensor (Figure 3). For security reasons, we established physical limits on the metal bar to restrict accessibility to noxious temperatures. None of the participants were harmed during the procedure.

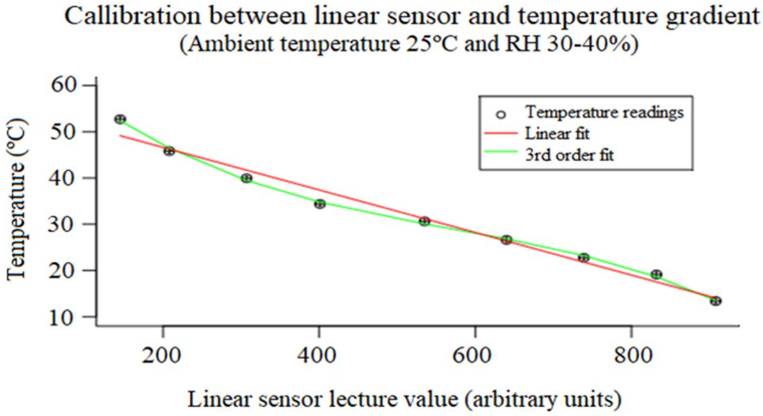

Figure 3. Linearity check of the temperature gradient along the metal bar. The x-axis represents the position on the linear sensor. This sensor is parallel to the metal bar, so the real length or position on the bar are not required to perform the mapping (Arduino analog-to-digital readings use 10 bits to store the readings —10 bits are 2^{10}, from 0 to 1024 values). The y-axis represents the local temperature in Celsius degrees (ºC). This was performed at a standard room temperature of 25ºC and with a relative humidity of 30-40%.

RESULTS

To understand the relationship between the reported sensations and the actual temperature of the device, we plotted the *'perceptual change points'* (e.g. from VC to C) against the temperature measured by the device at the points where people stopped sliding their finger (Figure 4a). As expected, we found a monotonic increase in the temperature at which people reported a change in sensation from Very Cold to Painfully Hot. None of the participants reported Painfully Cold (PC) sensations.

Interestingly, the standard deviations were low at each *'perceptual change point'*. They were between 1.5 and 4.0. This shows that participant responses were consistent when they determined the *'perceptual change points'*. This suggests that there is a common perceptual-qualitative scale across people.

To understand the relationship between the reported sensations and the estimated temperatures, we plotted the *'perceptual change points'* (e.g. from VC to C) against the *'estimated numerical values'* given by the participants at each point (Figure 4b). These values also follow a monotonic increase from Very Cold to Painfully Hot. The standard deviations were between 3.5 and 14, which are higher than in the previous case. There is a clear difference between the estimated temperatures and the real temperatures measured at the points in which people reported a temperature change.

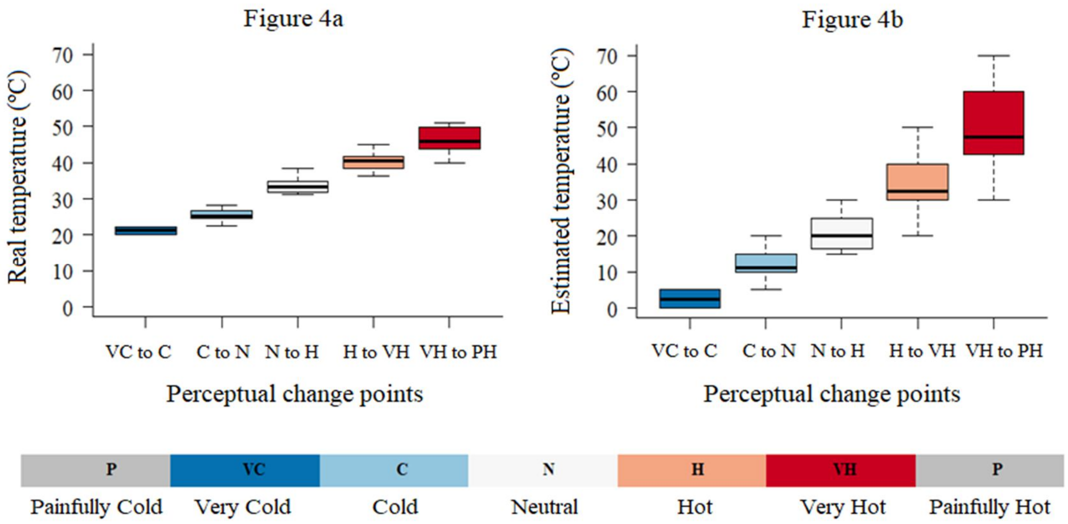

Figure 4. On the left, the Figure 4a: *'perceptual change points'* vs real temperatures. The x-axis represents the *'perceptual change points'* (e.g., from VC to C). The y-axis represents the temperatures registered by the device. On the right, the Figure 4b: *'perceptual change points'* vs estimated temperatures. The x-axis represents the 'perceptual change points' (e.g., from VC to C). The y-axis represents the 'estimated numerical values' in degrees Celsius given by the participants.

A closer statistical analysis was carried for each *'perceptual change point'* between the device temperature scale and the estimated temperature. First, the mean values were analysed with a student's t-test. In the cold and neutral range, the estimated values are significantly lower (t(14), $p < .05$) than the temperatures measured by our device. This fact suggests that we tend to overestimate negatively the cold and neutral sensation range.

A second analysis about the precision of the estimated scale is made by comparing variance with Fisher’s F-tests. The temperatures from the perceptual-qualitative scale and the estimated ones have a significantly different dispersion (F(7,7), $p < .05$) in the hot range. In other words, the responses in the estimated numerical scale are much more spread.

DISCUSSION AND CONCLUSIONS

Our results show that the temperature at which participants detected a change of sensation was consistent (Figure 4a). This suggests the existence of a common perceptual-qualitative scale and an agreement in how it is reported. This perceptual categorisation of thermosensation (VC, C….VH & PB) is present in other perceptual systems (Ashby & Spiering, 2004), and is in line with research on thermoTRPs and thermosensitive fibres (Ezquerra-Romano & Ezquerra, 2017).

Interestingly, the numerical estimations follow a different pattern. Firstly, the estimations differ more significantly from the real temperature values in the cold and neutral ranges. Secondly, the spread of these estimations increases monotonically with temperature (Figure 4b). Therefore, people identify the *‘perceptual change points’*, recognise the physical quantity temperature and its units, but they do not seem to correctly estimate their values. This means that they lack an appropriate representation of this variable. This is in line with the hypothesis that the ambiguity of the sensory signals is a contributing factor in the development of misconceptions (Ezquerra & Ezquerra-Romano, 2018; Kubricht et al., 2017).

The consistency of the *‘perceptual change points’* indicates that we have a common perceptual-qualitative thermal scale. This perceptual categorisation arguably underlies our temperature estimations. However, there is a greater variability in the numerical estimation of temperature compared to the *‘perceptual change points*. We propose that this mismatch is a product of differences in the learning process.

The presence of this mismatch poses a challenge for teaching and learning concepts about temperature. In this sense, teaching staff should understand the physiological and perceptual bases of misconceptions to tackle the learning difficulties of their students more effectively (Ezquerra & Ezquerra-Romano, 2019). Finally, we propose that teachers should develop activities to highlight the mismatch between thermal sensations and estimations. During these activities, students should connect the real temperature of objects with their thermal sensations and estimations. Thus, students would realise their difficulties in making thermal estimations and they would reflect on the way they developed concepts about heat, “cold” and temperature.

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REFERENCES

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. https://doi.org/10.1080/02635143.2014.987744

Albert, E. (1978). Development of the concept of heat in children. *Science Education*, *62*(3), 389–399. https://doi.org/10.1002/sce.3730620316

Ashby, F. G., & Spiering, B. J. (2004). The Neurobiology of Category Learning. *Behavioral and Cognitive Neuroscience Reviews*, *3*(2), 101–113. https://doi.org/10.1177/1534582304270782

Campillos, R., & Ezquerra, A. (2020). *Termosensímetro y método de medida de sensación térmica mediante gradiente térmico lineal* (Spanish Patent No. 202030815).

Chiappetta, E. L., & Koballa, T. R., Jr. (2014). *Science Instruction in the Middle and Secondary Schools* (8.a). Pearson Education.

Clough, E. E., & Driver, R. (1985). Secondary students' conceptions of the conduction of heat: Bringing together scientific and personal views. *Physics Education*, *20*(4), 176–182. https://doi.org/10.1088/0031-9120/20/4/309

Driver, R. (1989). Students' conceptions and the learning of science. *International Journal of Science Education*, *11*(5), 481–490. https://doi.org/10.1080/0950069890110501

Dyck, P. J., Zimmerman, I. R., Brien, O. ', C., P., Ness, A., Caskey, P. E., Karnes, J., & Bushek, W. (1978). Introduction of automated systems to evaluate touch-pressure, vibration, and thermal cutaneous sensation in man. *Annals of Neurology*, *4*(6), 502–510. https://doi.org/10.1002/ana.410040605

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

Ezquerra, A., & 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), 1–11. https://doi.org/10.29333/ejmste/97198

Ezquerra, A., & 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*, 012038. https://doi.org/10.1088/1742-6596/1287/1/012038

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. https://doi.org/10.1515/revneuro-2016-0039

Ezquerra-Romano, I., Ezquerra, A., & Agen, F. (2019). Do misleading thermal sensations underlie some heat and cold misconceptions? In O. Levrini & G. Tasquier (Eds.), *Electronic Proceedings of the ESERA 2019 Conference. The beauty and pleasure of understanding: Engaging with contemporary challenges through science education: Vol. Part 1 (co-ed. A. De Ambrosis Vigna&O. Finlayson),* (pp. 26–33). ALMA MATER STUDIORUM – University of Bologna.

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), 196–208. https://doi.org/10.1016/j.pain.2007.11.013

Kubricht, J. R., Holyoak, K. J., & Lu, H. (2017). Intuitive physics: Current research and controversies. *Trends in Cognitive Sciences*, *21*(10), 749–759. https://doi.org/10.1016/j.tics.2017.06.002

Patapoutian, A., Peier, A. M., Story, G. M., & Viswanath, V. (2003). ThermoTRP channels and beyond: Mechanisms of temperature sensation. *Nature Reviews Neuroscience*, *4*(7), 529–539. https://doi.org/10.1038/nrn1141

Piaget, J. (2007). *The child's conception of the world*. Rowman & Littlefield.

Tiberghien, A. (1985). Heat and temperature: Part B. In E. R. Driver, E. Guesne, & A. Tiberghiem (Eds.), *Children's ideas in science* (1.a, pp. 67–84). Open University Press.

Vosniadou, S. (1994). Capturing and modeling the process of conceptual change. *Learning and Instruction*, *4*(1), 45–69. https://doi.org/10.1016/0959-4752(94)90018-3