Heat is Cool: Improving Student Understanding of Heat and Temperature

Scott Skanes

University of British Columbia

Table of Contents

Problem Area

Students have a **lot** of alternative conceptions about heat and temperature. For example, students tend to think of "everyday heat" and "science heat" differently (Wiser & Amin, 2001). They have trouble conceptualizing thermal equilibrium, they believe that skin or touch can determine temperature, and memorize statements such as "heat rises" without truly understanding what they're talking about in any nuanced way. Having taught thermodynamics concepts at the junior high, high school and college level I always encountered students with "alternative conceptions" of heat and temperature, such as "wool acts to warm objects", but research in the area was never explored. After beginning a search for said research at the outset of this assignment, I came across a wealth of evidence proving what I assumed all along: there's a problem here, folks, and it extends from the moment students encounter the concepts all the way through university and beyond (Chu, Treagust, Yeo & Zadnik, 2012).

"Introductory Thermal Concept Evaluation: Assessing Students' Understanding"

If there is one conclusion that can be made about heat and temperature it's that "alternative conceptions" abound! Researchers Yeo & Zadnik (2001), for example, identified 26 separate conceptions in total, leading to developing the Thermal Concepts Evaluation, or TCE; an evaluation best suited for assessing students' understanding of introductory thermodynamics appropriate to the high school level. These researchers later formed a team of four to produce the "Evaluation of Students' Understanding of Thermal Concepts in Everyday Contexts" (Chu, Treagust, Yeo & Zadnik, 2012) which I also reference frequently.

"Is Heat Hot?"

I came across numerous relevant articles in my research, each reinforcing the original assumption that there is a need for support in this area. One of these articles was "Is heat hot?" written by Wiser & Amin (2001). This article focuses heavily on how student conceptions of heat are often centered on "hotness", meaning it is measured by temperature, which makes their differentiation of the two concepts nearly impossible. These researchers argued that "viewing energy as being summed over and distributed among molecules makes it extensivity easy to grasp". This article lead me down the path of wishing to design a lesson that would ingrain a strong conception of "distributed energy" in the minds of students and helped me design a lesson related to thermal equilibrium.

"A review of selected literature on students' misconceptions of heat and temperature"

The literature review compiled by Mustafa Sözbilir proved an invaluable resource for helping organize my thoughts in terms of which alternative conceptions to tackle for this assignment. In addition to eloquently summarizing important findings from studies on student understandings of heat and temperature, he made efforts to detail possible sources of student misconceptions which helped inform my lesson design. He summarized debates on heat and temperature terminology, noting how "nearly all text books [sic] which deal with heat offer different explanations of the term" (Sözbilir, 2003, p. 25). This echoed Bauman's (1992) concerns, who also blamed teachers' inadequate knowledge and the inherent conceptual difficulty of the topic. Finally, Sözbilir made a list of common misconceptions identified across over eight studies and organized them by student age, which proved invaluable for guiding my selection. I leveraged this guidance and chose to focus on students 15-years of age and above, although this was more of a guidepost than a strict rule I forced myself to follow.

Conclusions about Scholarly Articles Encountered

Firstly, not all scholarly articles used as inspiration, guidance, or “handbooks” for approaching my TELE design were summarized above. However, they serve as a good sample of what inspired my approach. The extent to which researchers had identified student conceptions of heat and temperature was overwhelming, yet the clarity in which they summarized important areas needing improvement, addressed commonalities among students, and provided guidance served as a basis for all of my work.

Design of a Learning Experience

My approach to this TELE assignment was to design a website, for teachers, in order to help them improve their students’ conceptions of heat and temperature. This was done by creating a series of three in-depth lessons for them to use. The lessons are designed almost like small workshops, and each lesson could go on for numerous sessions. The lessons are meant to be delivered in a face-to-face environment. A website was chosen to host the materials due to its ease of accessibility, especially because it can be easily searched online. A website also serves as a perfect hub for accessing all learning materials relating to the lessons, such as Google Docs, Forms, and Sheets, embedded content such as Scribd, Windows Installers for simulations, zip files, and links to external websites. It also allowed for a greater level of engagement in terms of the visual nature of the materials; GIFs and embedded YouTube videos were able to be incorporated with little to no effort.

It was quickly realized that it would be impossible to tackle all 26 alternative conceptions identified by Yao & Zadnik (2001) in three lessons, no matter how elaborate. As such the conceptions were filtered to six, chosen due to their pervasion into the TCE evaluation items as well as age-appropriateness, with a focus on ages 15 and above. The conceptions chosen are as follows:

- Objects of different temperature that are in contact with each other, or in contact with air at a different temperature, do not necessarily move toward the same temperature.
- Skin or touch can determine temperature.
- Perceptions of hot and cold are unrelated to energy transfer.
- Heat only travels upward.
- Heat rises.
- Heat and cold flow like liquids.

The intent of the design of the learning experience from the very beginning was to engage students in the content as fundamentally as possible, with technology leveraged as a tool with which they could explore more deeply. Student-centred inquiry was essential to the approach, and lessons were designed and scaffolded to promote discussion, collaboration, and reflection at all stages of the process. I am of the strong opinion that students should construct their own knowledge, not simply memorize, which is why almost every activity designed for the lesson series is hands-on or interactive in some way. Teachers using these lessons are meant to guide and to facilitate; not to act as knowledge gatekeepers.

Pedagogical Framework

T-GEM, a framework based on the Technological Pedagogical Content Knowledge (TPACK) framework (Koehley & Mishra, 2009), was chosen as the primary pedagogical foundation upon which the TELE was designed. I knew from the beginning of this assignment that I wanted to make extensive use of The Concord Consortium's "Energy2D" simulations tool (Xie, C. (2012), and Khan's (2011) "model-based", data-driven approach to student-centred inquiries seemed a perfect match. For the uninitiated, the T-GEM teaching approach involves a cycle of students **G**enerating, **E**valuating, and **M**odifying relationships based on their experiences with and manipulations of compiled data. The teacher serves as the driving force behind students making connections, guiding them to evaluate those connections in light of new information, as well as helping them modify their conceived connections based on the evaluations they made in the previous step. It is prescriptive but not to a fault, allowing designers to incorporate the affordances of social learning into their lessons and to help make learning visible (Linn, 2003). It's a practical, adaptable model which closely emulates the approach "real" scientists take when working with data, and one that students benefit extensively from.

To this end, the structure of T-GEM encourages allowing students to deeply explore concepts using complex models which is where the "T" in T-GEM, "technology", shines. Students tend to view models as "useful tools for testing and experimentation when performing simulation runs (Magana et al., 2017, p. 368), and T-GEM's focus on generating relationships and interpreting results helps students to make abstract concepts visible.

Pedagogical theories and foundations aside, the lessons, at their core, are meant to force students to physically explore the processes related to heat and temperature, to interact, to think critically, to reflect, to discuss with one another, to test the limits of each other's understanding and to revise their interpretations as often as necessary.

Pedagogical Goals

As mentioned above, the website and accompanying learning materials for this TELE are meant to help students with six clearly identified conceptions. These conceptions relate to three broad goals which are elaborated on within the website.

1. Objects at different temperatures in contact with each other move toward the same temperature.
2. Skin or touch cannot determine temperature; it can only tell you how quickly an object conducts energy towards or away from you.
3. "Heat" is not a substance.

Digital Technologies

A wide range of digital technologies were incorporated into the design of the TELE in order to support the goals listed above. Each technology was selected due to its perceived affordances for students, and often for their abilities go beyond simple substitution toward of tasks with the hopes to augment, modify, or transform the learning experience using technology (Romrell, Kiddler & Wood, 2014). What follows is a sampling of the technologies used.

Google Apps - Docs, Drive, Forms, and Sheets

Google apps allow documents and to be created and stored in the cloud. There, they can be assessed by anyone with permission, anywhere in the world with an internet connection, on any device including mobiles. This allows students and teachers to assess the documents independently of a given device. Teachers can use Google Forms to collect assessment data from anywhere, and export it easily, while Docs and Sheets allow students to collaborate in real time (Keeler & Miller, 2005).

Energy2D

Energy2D is an interactive, visual multiphysics simulation program that models conduction, convection, radiation and particle dynamics without the complexity of typical computational fluid dynamics simulations. Having been designed to be used by novices and experts alike, it allows students and teachers to design experiments, and test hypotheses or relationships, without the need for complex mathematics (Xie, 2012). These simulations allow students to explore visualizations of the fundamentally invisible processes involved in heat transfer and temperature, allowing deeper engagement and a reduction in menial learning tasks disconnected from real-world experiences (Finkelstein, Perkins, Adams, Kohl, & Podolefsky, 2005; Khan, 2011). Energy2D allows for immediate feedback that emerges naturally from the interaction with the tool. Custom applets created within this program which include probing questions, coupled with physical discrepant events linking the content to the real-world, make for extremely memorable student learning experiences

GIFs, Videos, and Screencasts

Visual learning aids are incorporated throughout the TELE for many reasons. Three of these will be detailed here. First, visuals are immediately more engaging than text, and animated visuals often more so. GIFs were used strategically throughout the site to help provide “energy” (excuse the pun) without included so many as to be overwhelming or distracting. Second, visuals were included to aid teachers understand what was meant by the lesson designer to support their delivery of the lesson. Third, videos and screencasts were included as learning tools both for the teachers and the students to understand how the technologies should be used.

The TELE Artefact Itself

Anyone can access the “Heat is Cool” TELE website designed for this assignment:

http://heatiscool.weebly.com

Please enjoy!

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