Developing a Concept of Thermal Equilibrium

What's this lesson all about?

The purpose of this lesson is to help students conceptualize that objects at different temperatures in contact with each other move toward the same temperature. It should also help students see that all objects, even objects like flour, sugar, and air, can heat up; it just takes a long time.

This lesson was designed after learning that many students, especially those in the 15-18 year-old range, do not have a conception of thermal equilibrium (Sözbilir, M., 2003). The misconception is so prevalent that it relates to 8 of the 26 questions contained on the TCE (Yeo & Zadnik, 2001), as seen below:

• Objects of different temperature that are in contact with each other, or in contact with air at different temperature, do not necessarily move toward the same temperature. (Thermal equilibrium is not a concept.)	1, 2, 3, 6, 9, 10, 17, 24

The structure of this lesson is meant to help teachers facilitate a lesson with their students. Throughout, allow students to explore, to be curious, to ask questions! The lesson will look slightly different for every class, depending on the particular setting.

This lesson should take place after the TCE Pre-Test.

Introductory Physical Activity - Taking Temperature

Materials: Thermometers (digital preferred), a variety objects scattered throughout the room whose temperatures can be measured

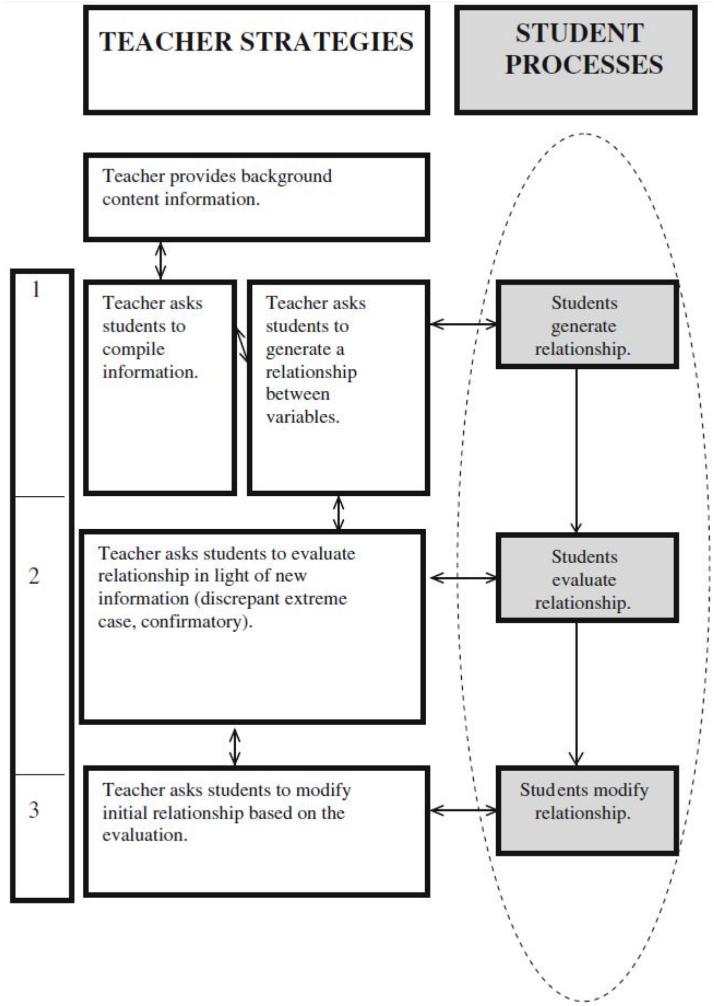
- Start by asking questions such as "which objects in this room as cold? Which are warm? Why?"
- Have students explain their reasoning to you or to each other. Do not correct them if their reasoning is imperfect.
- Instruct students, in groups or individually, to explore the room and take the temperature of 3-5 different items that are laying out. They should record their results in a table -- you can make a copy of this template or create make your own.
- Once data has been recorded in Google Sheets or somewhere else, have a whole class discussion about the results. Was it what they expected? Why, or why not? Were some temperatures higher than expected? Some lower? Were they all similar? Try to let students lead you.
    - **Note:** It is quite likely that, depending on the thermometer used, the temperatures of objects in the room will **not** be at room temperature. This is OK. Try to elicit reasoning from your students as to why this might be.
    - Examples: Object is close to window, object measured was not left in the room long enough, etc.
- The whole idea is to try to get students to see that if objects are in contact with the same temperature air in a room they **should** all reach the same temperature. Heat sources, like the human body, don't apply.

Teaching through T-GEM

If support is needed for using the Energy2D tool, please see the "Teacher Resources and Tutorials" section of the website.

The rest of this lesson plan is supported using the Energy2D simulation tool, and follows a structure guided by T-**GEM** (Khan, 2011). The procedure involves **T**echnology at each stage and students taking part in the following cycle:

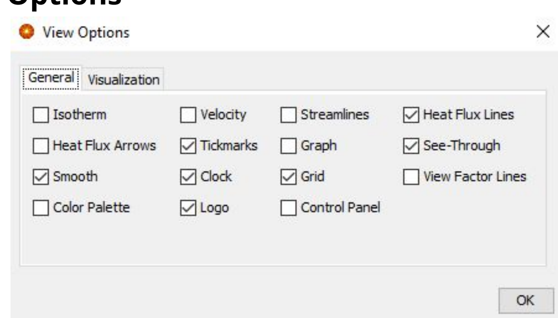
1. Compile Information
2. **G**enerate Relationship(s)
3. **E**valuate Relationship(s)
4. **M**odify Relationship(s)



You can use the following plan as a guide for your own lessons. Please feel free to adapt/modify it for your particular group of students, supplement it with additional inquiry questions, and/or reduce the level of complexity. The end of this document contains suggestions for guiding questions to help students to think critically.

Finally, you'll find numerous references to having students compare data, results, predictions, and so on. This can be as informal or formal a process as you feel is best, but I have found it useful to keep track of data-driven lessons using Google Sheets. It allows large sets of data to be compared, and for students to collaborate easily. Feel free to use this template as a sample for how you may want to approach student-student collaboration.

Major Phase of (T-)GEM	Main Teaching Methods	Teacher Guidance Strategies	Computer Simulations
Compile information	Ask students to compile information from a given simulation	Demonstrate how to access graphs, interpret them, gather and export data from virtual sensors	Teacher initially constraints simulations used to those using only one or two virtual thermometers Suggested Examples: conduction-test.e2d identical-heat-capacity.e2d
	Ask students to manipulate and track temperature of two different virtual objects	Demonstrate how to set temperature for each object manually in Energy2D	Teacher uses the applet to demonstrate technique to students, or has them view the tutorial video.

Generate relationship (**G**)	Identify variables for students (Temperature, time, thermal conductivity, direction of heat transfer)	Limits scope of variables to explore	Encourage students to explore a number of different simulations involving conduction where temperature and thermal conductivity are explored, in order to generate relationships between them. Suggested Examples: different-conductivity.e2d conduction1.e2d simpleheattransfer-custom.e2d
	Ask students to document their thoughts	Ask students to summarize relationships	Have students write down and discuss what they currently understand about the relationships between temperature, time, thermal conductivity, and direction of heat transfer.
	Ask students to find trends	Encourage students to make graphs, export, share and compare, and discuss their data using Google Sheets	Encourage students to focus on simple simulations involving a single thermometer and less materials before progressing to more complicated simulations involving or more thermometers or more complex materials. Once students are comfortable with the Energy2D program they should start working through the "simpleheattransfer-custom.e2d" simulation, found in the simulations folder. Students may use this Google Sheet to document and compare work: Heat and Temperature Activity Encourage students to explore **View Options** 
	Ask students about relationships between variables	Encourage students to make predictions and discuss variables with each other	
		Select extreme cases for student investigation	Students could be asked to select extreme variables (extremely high or low temperatures interacting, very small or very

			large conductivities)
		Ask students to compare results for similar experiments	Teacher could encourage have students log their work, either in a notebook or online using Google Sheets or Google Docs. The latter is recommended to allow sharing, collaboration and robust comparisons and discussions
		Ask students to explain	Teacher could ask students to compare the color of each object, how it relates to temperature, if it relates to heat, and to explain why heat may flow in one direction at one time and an opposite direction under different conditions
Evaluate the relationship (**E**)	Provide discrepant information	Ask students "Can objects below 0° C transfer heat?"	Teacher could encourage students to rerun experiments where two objects in contact are both "below freezing".
		Ask students "Can insulators like wool be used to keep things cold?"	Teacher could run a discrepant event cola cans, some wrapped wool, some not wrapped. If time allows for a side-activity, try this discrepant event: Conductors and Insulators
	Provide an extreme case	Ask students "What temperature will these objects reach?"	Teacher could set up the Simple Conductive Heat Transfer applet so that both objects have different thermal conductivities. Students have to predict the result (many will assume it's halfway).
		Ask students "why doesn't this work?"	Teacher could task students to make the heat transfer arrows flow from a lower temperature object to the higher temperature object. **(Spoiler Alert: Not Possible)**
	Provide a confirmatory case	Ask students to predict	Teacher could set up two materials with equal thermal conductivity and have students guess the equilibrium temperature (halfway)
		Do not correct students	Have students work together and continue sharing data to test the scope of the relationships they originally generated
		Ask students to compare	Task several students/groups with exploring the same applet to compare results and discuss relationships
Modify the		Ask students to revisit their	Have students reflect in writing or through

relationship (**M**)		original relationships between variables	discussion on how their original ideas did or did not hold up in the face of each new case
		Ask students to summarize relationships	Have students rewrite what they understand about the relationships between temperature, time, thermal conductivity, and direction of heat transfer, having them provide examples from activities Above all else, focus on having students explain what they know about temperatures objects reach after being in contact for a long period of time
		Ask students to solve a new case	**Extension 1:** Ask students to generate their own example/activity related to this topic for other students using the Energy2D applet's available tools. **Extension 2:** Ask students to form groups and come up with a minimum of 3 examples where the concepts covered could be related to real-life scenarios. **Extension 3:** Pose the following to students for discussion - "Imagine two balls, one small hot ball, and a big warm ball. They are dropped into identical cold water baths. Will one ball make its bath hotter than the other or will the two baths be at the same temperature?" (Wiser & Amin, 2001)

Grand Takeaway

Objects at different temperatures in contact with each other move toward the same temperature.

Again, this lesson can be modified to suit your needs, as it covers a large breadth of material. Not every aspect of what's explored above needs to be covered in-depth, but the teacher should ensure that students are questioned throughout the process. The lesson will be more effective if the teacher helps students make connections between the simulations and real-world analogies or situations.

Additional Teacher Guidance

Students should be encouraged to use examples from "real-life" as well as the simulations to support their responses to the questions below.

Question/Prompt	Brief Answer/Explanation
Do objects in contact always reach the same final temperature (thermal equilibrium)?	*Yes.*
Do objects in contact always reach thermal equilibrium at the same time?	*Yes.*
Is the final temperature of two or more objects in contact always the same?	*Yes.*
Is there heat transfer between two objects at the same temperature? For example, is there heat transfer between a wooden spoon and a metal spoon both at 30 °C?	*No… but this is not always the case. Sometimes there are outside factors such as air to which heat is being transferred to.* *There is also extensive heat transfer taking place during phases changes, with no change in temperature, but those concepts are beyond the scope of this lesson.*
How does thermal conductivity affect the rate of heat transfer?	*Heat transfer occurs at a high rate for objects of high thermal conductivity, and at a low rate for objects of low thermal conductivity.*
Are temperature and heat the same thing? (no)	*No. Heat is the transfer of energy, and the process by which hotter (higher temperature) objects warm cooler (lower temperature) objects.*
Is there a relationship between the temperature of two objects and the **direction** of heat transfer?	*Yes, it's always from higher temp to lower temp.*
Does heat always flow in the same direction between the same two objects?	*No, depends on each object's temperature.*
Does the material an object is made of have any effect on how objects are heated?	*Yes.*
Do all objects transfer heat, and reach thermal equilibrium when in contact with other objects? (e.g. flour, salt, air)	*Yes, although the material determines the rate of heat transfer.*

If you place many ice cubes in water and stir until the ice cubes are small but have stopped melting, what is the most likely temperature of the water?	*0 °C. If the ice cubes are not longer melting it means that the water is likely at the same temperature as the ice cubes and the water is no longer transferring heat to them.This would be around 0 °C.*
Why does a countertop feel cold after a cola can has been sitting on it for some time?	*Heat* ***from the countertop*** *has been transferred* ***to the cola can*** *to try and heat it. This lowers the temperature of the countertop; it also raises the temperature of the cola can.*

The next lesson is Lesson 2 - "Hot" and "Cold".

Final Notes:

- Please forward any feedback you have on this lesson to scottskanes@gmail.com. I'd love to hear what you liked, what you didn't, what worked, what didn't or any modifications you've made!
- All Energy2D files (.e2d) must be downloaded and opened in Energy2D before they will work.
- The team behind Energy2D is working on a more web-friendly version of their simulations. At the time of this writing this didn't exist, so Java was begrudgingly used because of the benefits of the tool.
- Until a mobile-friendly version of the tool exists, students should each (or in groups) have a computer/laptop/tablet that can run the software.