Conceptual resources students* use to reason microscopically about heat & temperature

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Theoretical Framework:

Resources are "seeds of science" that can lead to more sophisticated science ideas [1-3].

Methods:

Asked conceptual intro. physics questions at 4 colleges & universities*.

Analyzed responses and developed emergent coding schemes which identified 3 resources.

Coded 624 student responses for presence of 3 identified resources.

Conceptual Resources:

1. Differences will eventually even out
2. Macroscopic changes connect to microscopic collisions
3. When something is hotter, its molecules are moving faster

Implications:

- Supports the development of instructors' pedagogical content knowledge, particularly knowledge of students' ideas [4].
- Informs the development of ACORN physics tutorials, which elicit students' resources and build on them to support learning:

  www.physport.org/curricula/ACORN

Conceptual Questions:

When an ideal gas in a container with a moveable piston is heated so that the temperature goes up, the piston moves up. Use ideas about microscopic gas particles and interactions to explain why this happens.

When the temperature outside suddenly gets very cold, you find that the tire pressure in your car tires is low. How do you make sense of this, using something other than the ideal gas law?

Why does "heat" or "thermal energy" transfer from hot to cold objects, and not the other way around?

Student Responses:

"When the gas is heated, this gives the particles more energy and **they move with more speed** and collide with each other with more force. **Not only do they collide with each other with more force, but also the walls of the container and the piston. This is what causes the piston to rise**."

"**As temperature lowers, gaseous molecules move slower**. Therefore, **they hit the tire less frequently causing pressure to lower**."

"**The average thermal energy of the tire changes to match the average thermal energy of the surrounding environment.**"

"**In hot objects, the molecules are moving quicker**, and when in contact with **a colder object (in which molecules move slower) the collisions will all even out the speed of molecules and it will be more neutral as opposed to hot/cold**."

Prevalence:

	U1	U2	U3	U1	U4	U1	U3
Total N	258	18	39	89	37	159	24
% Micro	34%	56%	67%	83%	70%	51%	96%
1 (of micro)	36%	10%	23%	7%	4%	12%	0%
2 (of micro)	42%	80%	65%	80%	42%	36%	74%
3 (of micro)	65%	90%	92%	77%	96%	68%	91%

References:
[1] D. Hammer, Am. J. Phys. 68, S52 (2000).
[2] D. Hammer & E. van Zee, Seeing the Science in Children's Thinking: Case Studies of Student Inquiry in Physical Science (Heinemann, Portsmouth, NH, 2006).
[3] J.P. Smith, A.A. diSessa, & J. Roschelle, J. Learn. Sci. 3, 2 (1993).
[4] L. Shulman, Harv. Ed. Rev. 57, (1987).

Icons from the Noun Project: thenounproject.com

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* For more info on the demographics of our sample, scan the QR code to access the corresponding PERC paper.

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