Probing Middle School Students' Knowledge of Thermal Expansion and Contraction Through Content-Aligned Assessment

Cari F. Herrmann Abell and George E. DeBoer
AAAS Project 2061

Introduction: This poster describes how we use pilot testing during item development to gain insight into middle school students' thinking about thermal expansion and contraction. Students in grades 7-9 from two school districts in different parts of the country were given a set of 4 assessment items that are aligned to the idea of thermal expansion and contraction: *For any single state of matter, changes in temperature typically change the average distance between atoms or molecules. Most substances or mixtures of substances expand when heated and contract when cooled* (based on benchmark 4D/M3b, *Benchmarks for Science Literacy*, p. 78). The students were asked to chose a correct answer and then respond in writing to additional questions about the item, such as explaining why they thought an answer choice was correct or incorrect. From their written responses, we are able to determine: (1) whether students used the targeted idea to answer the question or if they used other knowledge or test taking strategies instead, (2) whether the item was comprehensible to them, and (3) whether the answer choices were plausible to them. Mismatches between the answer choices that students select and the reasons they give provide us with information about whether the item is likely to yield false positive or false negative results. Items, and the expectations we have for students, are then revised accordingly. Student responses also provide information regarding student misconceptions. This study is part of a larger project to develop an online collection of student assessment items in science that are precisely aligned with national standards.

Linking Macroscopic Phenomena to an Atomic/Molecular Explanation for the Contraction of a Solid

ITEM:

Version 1 (Atomic/molecular explanation only):
After cooking breakfast, a cook places a hot iron frying pan on the counter to cool. What happens as the iron pan cools?

A. The iron atoms get heavier.
B. The iron atoms decrease in size.
C. The number of iron atoms increases.
D. The distance between iron atoms decreases.*

Version 2 (Macro phenomena + Atomic/molecular explanation):
After cooking breakfast, a cook places a hot iron frying pan on the counter to cool. What happens as the iron pan cools?

A. Even though you cannot see it, the pan gets a tiny bit smaller because the iron atoms decrease in size.
B. Even though you cannot see it, the pan gets a tiny bit smaller because the distance between iron atoms decreases.*
C. Even though you cannot feel it, the pan gets a tiny bit heavier because the iron atoms increase in mass.
D. Even though you cannot feel it, the pan gets a tiny bit heavier because the number of iron atoms increases.

Results:

Version 1 Atomic/Molecular only	B (size)	D* (distance)	A (mass)	C (number)	Not Sure	Total
n	5	**18**	2	1	6	32
%	16%	**56%**	6%	3%	19%	100%

Version 2 Macro + Atomic/Molecular	A (size)	B* (distance)	C (mass)	D (number)	Not Sure	Total
n	2	**4**	6	3	15	30
%	7%	**13%**	20%	10%	50%	100%

Sample Written Comments for Version 2:

- "A frying pan can't get any smaller than it already is."
- "It could be D [heavier/number increases] because the others don't make any sense."
- "Because if every time you cooked with an iron pan and the atoms got smaller in a couple of years you would not have an iron pan anymore would you."

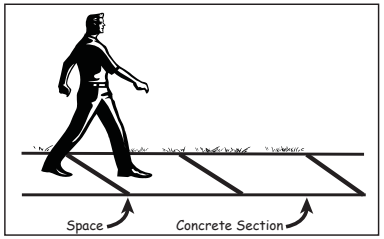
What we learned:

- Even if students have an atomic/molecular level understanding of the thermal contraction of solids, they may still have difficulty linking this knowledge to the corresponding macroscopic phenomenon of the solid getting smaller.

Predicting the Expansion of a Solid

ITEM:

Most sidewalks made out of solid concrete have spaces between the sections as shown in the diagram below. What happens to the width of the spaces during a hot day in the summer and why?



A. The spaces get wider because the concrete shrinks.
B. The spaces get narrower because the concrete expands.*
C. The spaces stay the same because the concrete does not shrink or expand.
D. Some spaces get narrower and some get wider because some concrete expands and some concrete shrinks.

Results:

	A (shrink)	B* (expand)	C (neither)	D (both)	Not Sure	Total
n	5	**11**	23	6	12	57
%	9%	**19%**	40%	11%	21%	100%

Sample Written Comments

- "I don't think concrete contracts because it is solid."
- "Concrete is a solid and doesn't shrink or expand."

What we learned:

- Many students did not know that solids can expand and contract. Most thought that solids cannot change size with changes in temperature.

Explaining the Expansion of a Liquid

ITEM:

The level of colored alcohol in a thermometer rises when the thermometer is placed in hot water. Why does the level of alcohol rise?

A. The heat molecules push the alcohol molecules upward.
B. The alcohol molecules break down into atoms which take up more space.
C. The alcohol molecules get farther apart so the alcohol takes up more space.*
D. The water molecules are pushed into the thermometer and are added to the alcohol molecules.

Results:

	A (heat molecules)	B (break down)	C* (distance)	D (water added)	Not Sure	Total
n	21	1	**20**	0	14	56
%	37%	2%	**36%**	0%	25%	100%

Sample Written Comments

- For A, "Because heat is the only [thing] that will make it rise."
- For A, "Because heat rises and it is being heated."
- For B, "The space between molecules expands with the increase in temperature."
- For B, "Heat causes molecules to speed up, causing them to get farther away."

What we learned:

- Students apparently were drawn to answer choice A not only because they believed "heat molecules" exist but because the answer choice used the word "heat" and students have learned that "heat rises."
- Students did not think that the molecules would break down when heated.
- Students were more likely to correctly explain this phenomenon they probably believed could happen (liquid expanding in thermometer) than to predict a phenomenon they believed couldn't happen (solid concrete expanding when heated).

Explaining the Contraction of a Gas

ITEM:

You drink all of the water from a plastic bottle. You put the cap on the bottle and leave the bottle outside during a cold night. When you go outside early the next morning, you notice that the bottle looks like it has been flattened as shown in the pictures below. What caused the bottle to change shape?

A. All of the molecules of the air went out of the bottle so there is nothing left in the bottle.
B. The molecules of the air inside the bottle got closer together so the air takes up less space.*
C. The heat molecules escaped from the bottle so there are fewer molecules left in the bottle.
D. The molecules of the air inside the bottle broke down into atoms which take up less space.

Results:

	A (air escaped)	B* (distance)	C (heat molecules)	D (break down)	Not Sure	Total
n	6	**24**	6	2	19	57
%	10.5%	**42%**	10.5%	4%	33%	100%

Sample Written Comments

- "If the cap was on the bottle the air couldn't escape."
- "This answer choice [C, heat molecules] is almost the same as A [molecules of air leaving the bottle]. That is why I'm positive they are both wrong."
- "The cool air would cause the molecules to get closer together and move more slowly."
- "A lower temperature decreases the space between molecules."

What we learned:

- Students did not think answer choices A and C (molecules leaving the bottle) were plausible because the item stated that the cap was on the bottle.
- Students were more likely to correctly explain this phenomenon they probably believed could happen (gas contracting in bottle) than to predict a phenomenon they believed couldn't happen (solid concrete expanding when heated).

Summary and Conclusions:

Pilot testing of assessment items during item development is a valuable tool for gaining information about students' knowledge and difficulties. From the 4 thermal expansion and contraction items presented on this poster, many students showed a good understanding of expansion and contraction at the atomic/molecular level. However, we found that this knowledge is often disjointed from the corresponding macroscopic expansion and contraction phenomena. We also observed that many students were less likely to correctly predict or explain phenomena that they did not believe could happen (the expansion or contraction of solids) than to explain phenomena they were told did happen and probably believed could happen (the expansion or contraction of gases and liquids). The information we gained from pilot testing will ultimately be used to improve the comprehensibility of the assessment items and enable us to test the full range of types of ideas that students have about thermal expansion and contraction, both at the atomic/molecular and macroscopic levels.

The authors would like to acknowledge the National Science Foundation for funding under Grants # ESI 0227557 and ESI 0352473.