

SIZE AND SCALE

An Investigation of Student Conceptions of Size

César Delgado¹, Shawn Stevens¹,
Molly Yunker¹, Namsoo Shin Hong¹,
Kelly Hutchinson², Emma Tervaarwerk³,
Joe Krajcik¹, Nick Giordano²

University of Michigan¹, Purdue University²,

WHY STUDY SIZE AND SCALE?

- Scale is one of four “common themes” in the Benchmarks¹
- Common themes unify content across grades, topics, disciplines
- Scale underlies critical principles in nanoscience and technology
- Considering widely varying ranges of variables (e.g., size) is the first step in learning about scale¹

FOUR CONCEPTIONS OF SIZE

Qualitative Relative: Order by size: $A > B > C > D > E > F > G > H > I > J$

Categorical: Group objects of “similar” size, order groups by size: $\{A, B, C\} > \{D, E\} > \{F, G\} > \{H, I, J\}$

Quantitative Relative: Object E is 1000 times smaller than object C

Absolute: Object E is 1 nm in length

RESEARCH QUESTIONS

- How do students and experts conceptualize the size of objects and the units with which to measure them?
- What do students know about very small objects and their size?
- What do developmental trajectories for conceptual understanding of size look like?

POPULATION

- 12 each 6th-7th, 9th-10th, 11th-12th, undergraduate; 4 experts
- 2X2 design (by gender, ability level/major)
- Middle and high school students from a racially diverse, low-mid SES small city
- 12 undergraduates, 4 experts from a research university

METHODOLOGY

Individual interview

- “What is the very smallest thing you can think of? (If macro: “Can you think a thing too small to see with the naked eye?”)
- “What type of measurement units would you use to express the size of that object?”

10-card sort tasks

- Order by size (qualitative relative)
- Group by size (categorical) - “Make groups of objects of similar size. Make as many groups as you think makes sense.”

5-card sort tasks

- “How many times bigger/smaller is each object than pin head?” (quantitative relative)
- “What size is each object?” (absolute)

PRELIMINARY FINDINGS, 9th-10th graders

Interview (N=9)

| Smallest Object | Initial | Final |
|----------------------------------|----------------|--------------|
| Atom/part of atom, molecule | 3 | 6 |
| Cell/part of cell, microorganism | 2 | 3 |
| Macro object (visible to eye) | 4 | 0 |

- Suggests knowledge from science instruction is often “inert”, as some students recall science concepts only after being prompted

| Measurement Unit | # of Answers |
|----------------------------------|---------------------|
| Nanometer | 1 |
| Fraction of inch (billionths) | 1 |
| mm or cm | 4 |
| Don't know/wrong unit (Newton·m) | 3 |

- Appropriate units for thinking about the nanoscale are not available to most 9th-10th graders in the sample

10-Card Sort Tasks (N=15) - Used the cards shown above

- Ordering by size (qualitative relative):

| Responses | # of Answers |
|--|--------------|
| Errors in macro objects (Earth-pin head) | 0 |
| Macro right; errors in order of cell, atom | 3 |
| Macro, cell, atom right; errors in other micro | 12 |
| All objects ordered correctly | 0 |

- Micro (cell through atom) is harder for students than macro
- Cell and atom - central science concepts - were usually ordered correctly relative to each other and to macro objects
- Grouping by size (categorical): Analyze using
 - Grounded theory²
 - Tretter et al's categories³
- One student made groups with non-contiguously ranked items:
{A, B, D} > {C, E}
 - Shows lack of integration of qualitative relative and categorical conceptions of size

5-Card Sort Tasks (N=17) - Used the cards shown below

- How many X bigger/smaller than pin head (quantitative relative)
 - 9th-10th graders tend to underestimate size differences between micro objects and pin head
 - Wide variation: atom estimates range from 8 to 1 billion times smaller than pin head, Earth from 80 to trillions of times larger
 - Accuracy is low for all objects: ~20% of ratios are within 10X
- Size of each object (absolute)
 - Size of human easiest; ~50% had size in metric units within 10X
 - Other objects' accuracy low: ~20% within 10X of correct value
 - One student used negative numbers of mm for atom and cell
 - 3 students assigned sizes ≥ 1 mm to objects they had ranked smaller than a 1mm pin head (size was given); this shows lack of integration of qualitative relative and absolute conceptions of size
- Students less likely to finish absolute than quantitative relative task
- Only 1 student had congruent, integrated answers on both 5-card tasks, despite students having answers from first task available
- 11 showed no integration, e.g., cell is 1000 X smaller than 1mm pin head, but cell is 1/2 mm
- 6 had integrated answers on some objects only
- This shows widespread lack of integration of quantitative relative and absolute conceptions of size

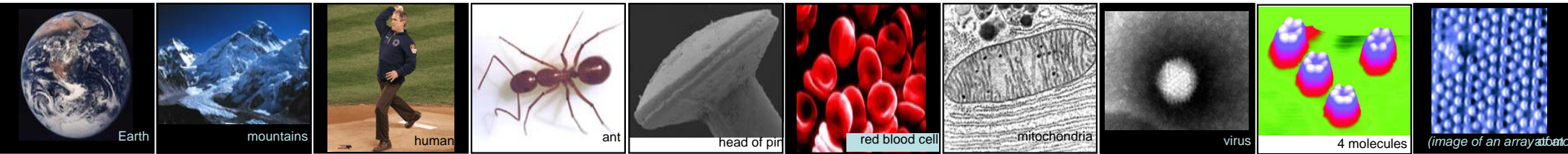
MAJOR FINDINGS

- 9th-10th graders know about atoms, cells, and their relative sizes, but their knowledge may not be readily accessible. Most do not know units with which to express their size.
- Students do not always make connections among different conceptions of size. Some connections are more common than others in the age group studied
- Future work with various age groups will trace the path(s) of integration of size conceptions in students
- Future work with experts will inform learning outcomes for students
- Identifying learning progressions for size can impact curriculum development by:
 - signaling what concepts are appropriate to introduce at each age group
 - guiding the development of activities that scaffold students in constructing a more integrated and robust idea of size

References

- 1) American Association for the Advancement of Science. (1993). *Benchmarks for science literacy*. New York: Oxford University Press.
- 2) Strauss, A., & Corbin, J. (1998). *Basics of qualitative research: Procedures and techniques for developing grounded theory*. 2nd edition. Thousand Oaks, CA: Sage.
- 3) Tretter, T.R., Jones, M.G., Andre, T., Negishi, A., and Minogue, J. (2006). Conceptual boundaries and distances: Students' and experts' concepts of the scale of scientific phenomena. *Journal of research in science teaching* 43(3), 282-319.
- 4) Confrey, J. (1991). Learning to listen: A student's understanding of powers of ten. In E. von Glasersfeld (Ed.). *Radical constructivism in mathematics education* (pp. 111-138). Dordrecht, The Netherlands: Kluwer Academic Publishers.

Objects for 10-card sort



13 000 000 000 X

1 000 000 X

1 800 X

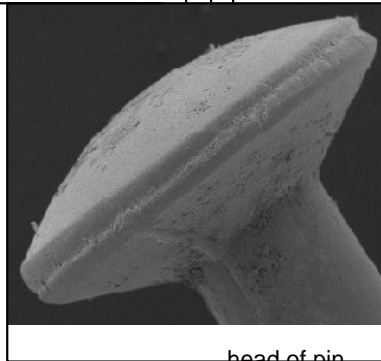
1 000 X



Earth

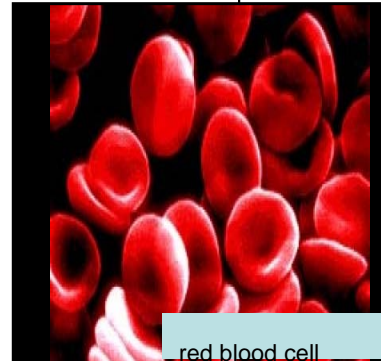


human

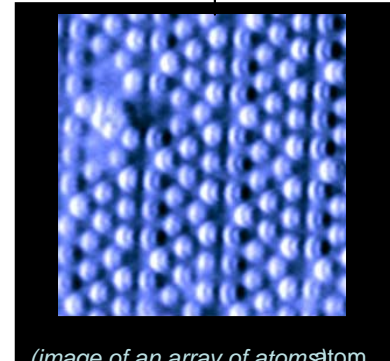


head of pin

1 mm



red blood cell



(image of an array of atoms)