SIZE AND SCALE
An Investigation of Student Conceptions of Size

César Delgado[1], Shawn Stevens[1],

Molly Yunker[1], Namsoo Shin Hong[1],

Kelly Hutchinson[2], Emma Tervaarwerk[3],

Joe Krajcik[1], Nick Giordano[2]

University of Michigan[1], Purdue University[2],

WHY STUDY SIZE AND SCALE?

- Scale is one of four “common themes” in the Benchmarks[1]
- 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 scale[1]

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 6^{th}-7^{th}, 9^{th}-10^{th}, 11^{th}-12^{th}, 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 theory[2]
  – Tretter et al's categories[3]
- 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 $\geq$ 1mm 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

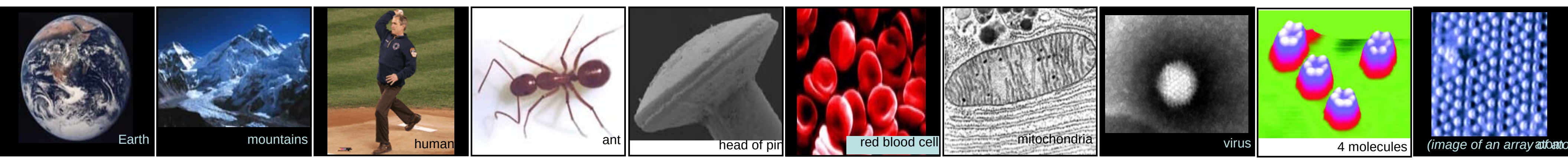
1) American Association for the Advancement of Science. (1993). *Benchmarks for science literacy.* New York: Oxford University Press.

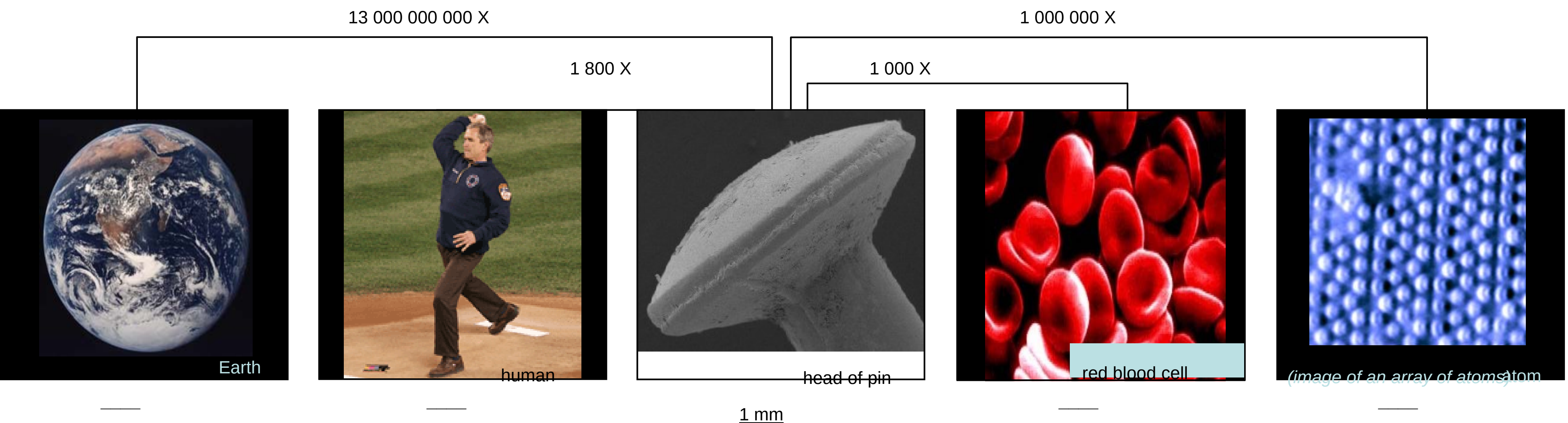
2) Strauss, A., & Corbin, J. (1998). *Basics of qualitative research: Procedures and techniques for developing grounded theory*. 2nd ediction. Thousand Oaks, CA: Sage.

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
1 800 X
1 000 000 X
1 000 X
Earth
human
head of pin
red blood cell
(image of an array of atoms)
atom
1 mm