How do undergraduate students studying nanoscience understand "size and scale”?

Results from an exploratory interview study

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Abstract

It is often assumed that undergraduate students come to college with a firm understanding of the concept "size and scale", a key idea to the learning of nanoscience. However, a preliminary interview study revealed that, contrary to this belief, many students have difficulty grasping the idea of "size and scale", particularly when non-visible objects are involved. In this talk, we will share our findings regarding the different types of understandings students construct for "size and scale", and discuss the development of assessment items that might capture such variations.

**Note: Part of the results reported here has been published in the Proceedings of ICREE 2007.*

Presentation Overview

- Interview study to explore students' conception of *Size and Scale*
- Development of assessment items based on the results of the interview study

Why *Size and Scale?*

- *Size and Scale* has been identified as one of the “big ideas” of nanoscience (Stevens et al., 2007)
- Contrary to common beliefs, undergraduate students, even engineering or science majors, are reported to have difficulty in mastering this concept (e.g. Drane et al., 2008)
- Previous research on *Size and Scale* has not examined undergraduates’ conception of this big idea (Tretter et al., 2006)

Purpose of Study

- To describe the variation in the ways in which undergraduate students understand or conceive the idea of *Size and Scale*

  Size, here, refers to the actual extent or amount of something Scale, on the other hand, links the size of a phenomenon to conventionally defined numerical representations of size.

  “Conceptions are “specific meanings attached to phenomena which then mediate our response to situations involving those phenomena. We form conceptions of virtually every aspect of our perceived world, and in so doing, use those abstract representations to delimit something from, and relate it to, other aspects of our world” (Pratt, D. D. 1992).

- To explore possible barriers that prevent students from fully grasping this concept

Interview Study - Method

- **Participants:**
  - 12 undergraduate students at a major Midwest research university
    - 6 from a freshmen engineering course
    - 6 from a non-major materials science course
  - Participants chosen to maximize possible variation in conception
    - Chosen from larger pool of students stratified by results on a nanoscience size and scale inventory
    - Assessed as “above average”, “average”, and “below average”

- **Think-aloud interviews:**
  - Two related interview tasks:
    - Order a list of objects of widely varying sizes - Football field, elephant, textbook, human hair, bacteria, virus, & hydrogen atom
    - Apply appropriate numerical scale(s) to represent the relative size differences of these objects
  - Students were probed to explain their reasoning as they completed the tasks

Preliminary Findings:
Dimensions of Variation

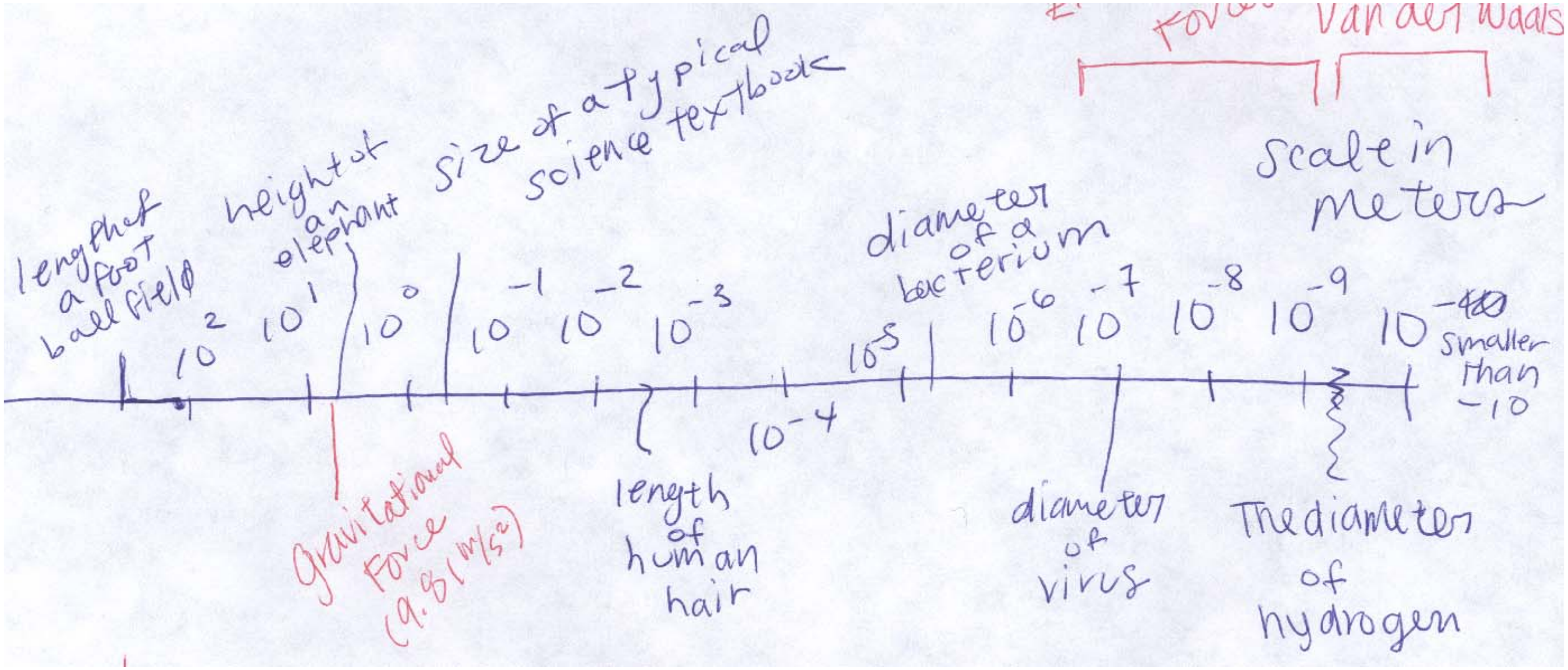
- Students' conception of *Size and Scale vary along the following three dimensions*:
  - Nature of continuum
    - Students' perception of whether objects of widely varying sizes, or objects belonging to different "worlds" can be represented using a continuous scale
    - Fragmented vs. Continuous
  - Nature of scale type used
    - Students' choice of numerical scale(s) that are most appropriate to represent objects of widely varying sizes
    - Logarithmic vs. Hybrid vs. Linear
  - Nature of understanding of the particular scale chosen
    - Coherence of students' understanding of the chosen numerical scale, and the real construction and/or meaning of the particular scale
    - Integrated vs. Detached

Preliminary Findings (cont.):

Preliminary Typology of Undergraduate Students' Conceptions of *Size & Scale*

Type	**Type-1**		**Type-2**	**Type-3**	
Sub-type	1a	1b	2	3a	3b
Nature of continuum	Continuous			Fragmented	
Category of scale used	Logarithmic		Hybrid	Linear	
Understanding of scale used	Integrated (Log level)	Detached (Log level)	Detached (System level)	Integrated (Number level)	Detached (Number level)
Main characteristics	1.Understood that the logarithmic scale is a "real scale that can be applied across the macro – sub-macro continuum. 2.Able to provide correct explanation for the log scale's construction (e.g. even spacing) and the advantage of using it.	1. Applied the logarithmic scale across the macro – sub-macro continuum. 2. Viewed the log scale as a "scientific" way of scaling, not a "real" scale. 3.Relied on memorization to construct it.	1. Understood that a scale could be applied across all sizes. 2. Applied a hybrid scale that included elements of both logarithmic and linear scales. 3.Able to provide primitive explanation for the advantage of using it; But unable to explain the log scale's construction (e.g. even spacing).	1. Held fragmented conception of scale across all sizes; Viewed the macro and sub-macro worlds as divided. 2. Applied the linear scale based on actual sizes. 3. Attempted to assign numbers to the scale	1. Held fragmented conception of scale across all sizes; Viewed the macro and sub-macro worlds as divided. 2. Applied the linear scale based on actual sizes. 3. No attempt to assign numbers to the scale

Example Type 1b (Detached Log) response:



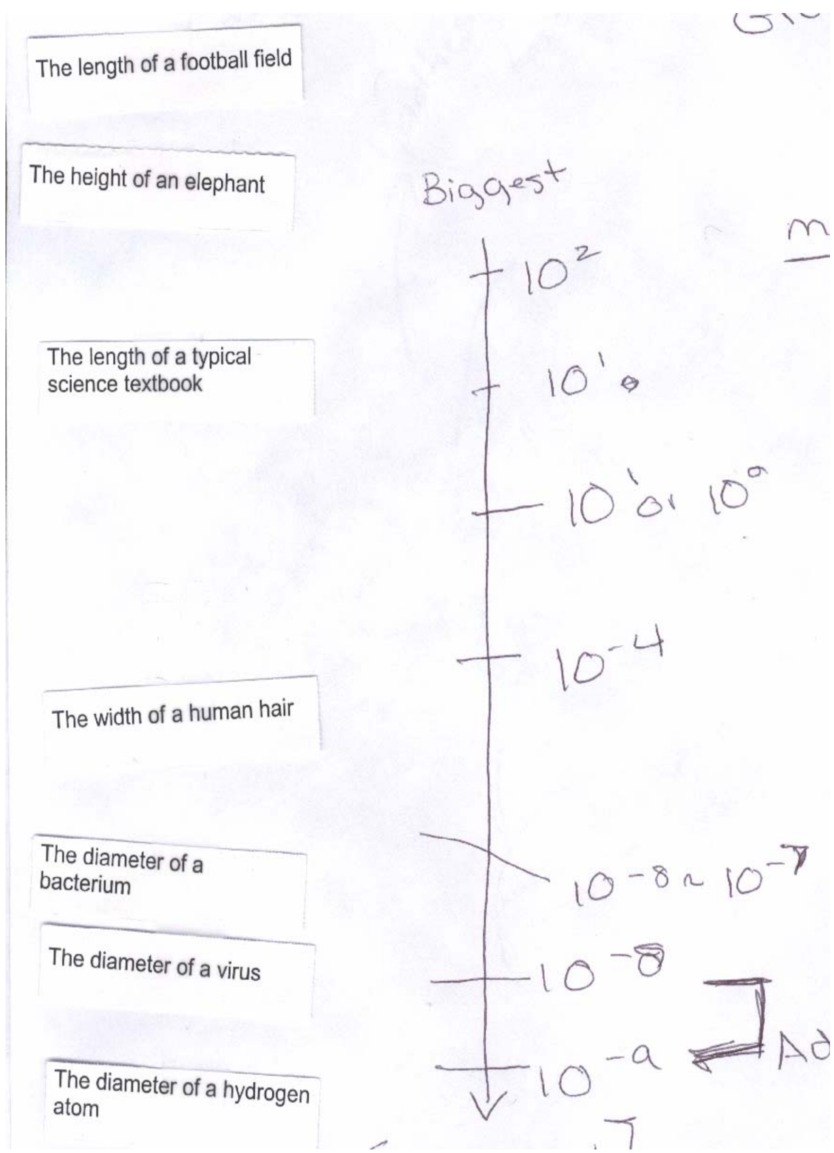
Interviewer: So what does each of these equal distances represent?

Student: I don't think it represents anything besides that it's in chronological order, but it just kind of represents a scale that people can see. I didn't, when I made it, I wasn't really thinking about making the markings, the difference between the markings, like the relative to the size. I just thought I'm going to put these in order and maybe in context.

Interviewer: That's fine. I'm just trying to understand a little bit better.

Student: ***Yeah, I don't know how to explain it. This is the way we've been shown the scale, like I've seen this scale at least 12 or 13 times. It's always like in this way. I know down here it gets so small that you can't really see the scale any more, but even here I think to just keep the consistency and not to confuse us, they do it so that it synchronized.***

Example Type 2 (Hybrid) response #2:



Student: It would be on the magnitudes of 10, for sure. Oh yeah, for sure.

Interviewer: And why do you think it's the best one?

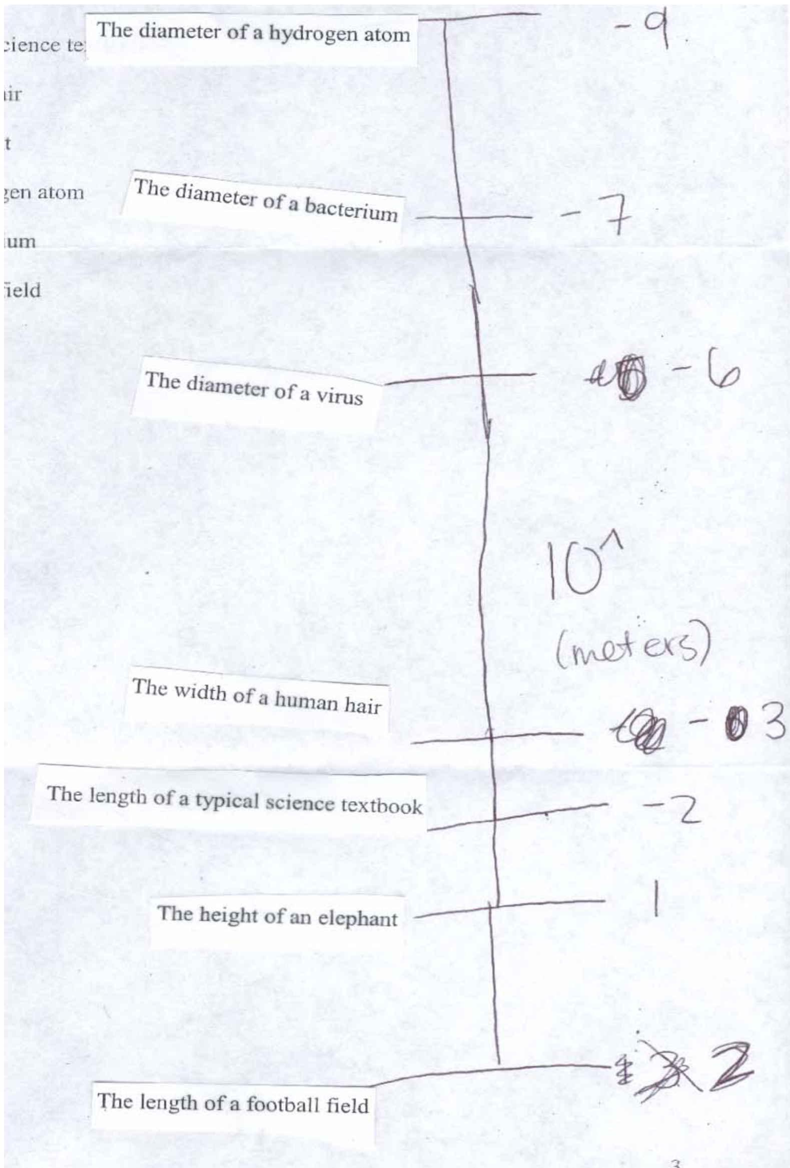
Student: I mean because conceptualizing it…it's hard for example to put any other certain numerical scale to the difference between a hydrogen atom and the length of a football field, and when you write like 10 to the something *(writing while talking)*, you have this other number to sort of judge it by, so it's always 10 to the something, 10 to the something. So ok, -4 is got to be smaller than 4, so obviously that's smaller…Why would put in that scale? I think you get a huge range, and for a standard, I think it's always going to be like 10. Did that answer it for you?

…

Interviewer: Ok? Just looking at the way you ordered them, some you've got a little closer…There is a little bit of variation to the length of the distance between…

Student:* *Oh that's just chance. If I were to make them more clumped together, it would be like these two would be together, the virus and the bacterium. The human hair would be kind of hang out around here. The science textbook would way out over here because you've got one hanging out between the two. So this is below 1, and that's above 1, so obviously makes a huge difference. The height of an elephant, maybe like that, like that, it's more picture, graphically accurate representation.

Example Type 2 (Hybrid) response #1:



Interviewer: So why did you choose, before you said that this is on the logarithmic scale, why did you choose the logarithmic scale here?

Student: The diameter of a hydrogen atom, in comparison with the length of the football field, is like, you can't use the same scale to compare them, because the hydrogen atom is so much smaller.

…

Interviewer: Ok. Could you explain it a little bit, like I see between some objects the space is smaller than others? Could you explain it?

Student: ***I think it's just might be my drawing of those, but I guess if I were to do it over again, these (pointing to the smaller objects) would be much closer together, and as it gets larger, they would spread out.***

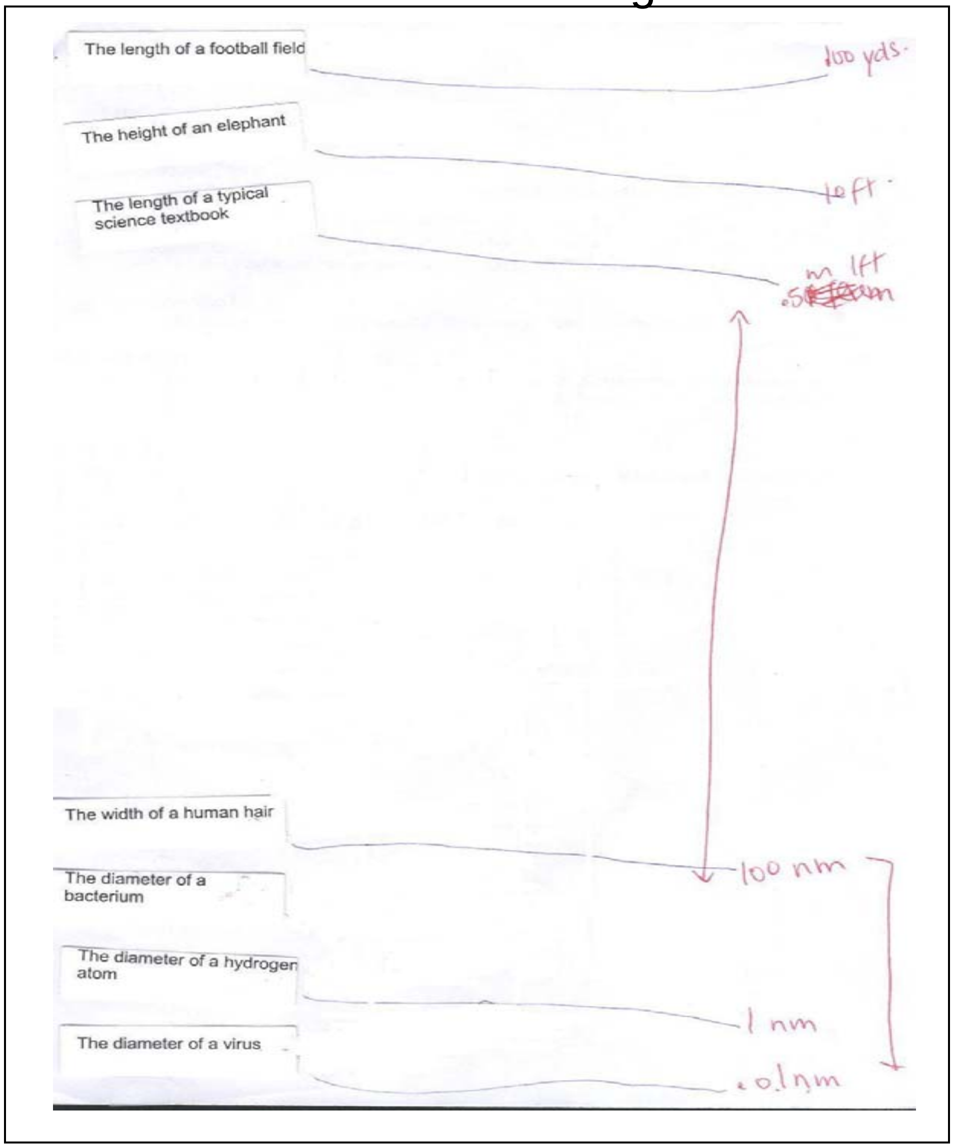
Interviewer: *Why would that be?*

Student: ***Because 1 meter is much bigger than 1 nanometer.***

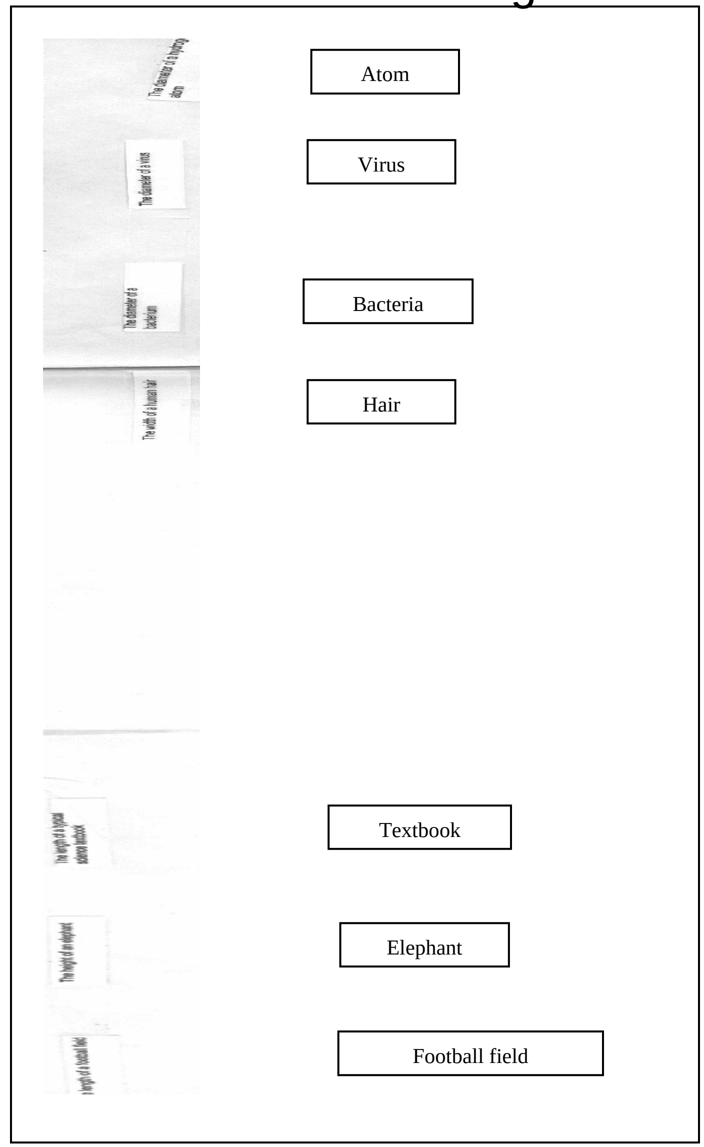
…

Example Type 3 (Fragmented) response:

3a With number integration:



3b Without number integration:



Preliminary Findings (cont.):
Possible learning barriers

- **Students' choice and explanation of their scale revealed a strong reliance on visual experience:**
  - Without direct visual experience, students seemed to have difficulty truly conceptualizing or comprehending objects that are invisible to the human eye.
  - The reliance on visual experience may also contribute to the belief of a separation of the "two worlds" - the macro (i.e. visible) vs. the sub-macro (i.e. invisible) world.
- **The use of the Imperial unit system in daily life and the Metric system in science context seemed to create unique barriers for American students to grasp the idea of *Size and Scale:***
  - Some students seemed to view objects typically measured/discussed using different unit system as belonging to separate, irreconcilable worlds.
  - To some students, the log scale seemed to be situated only within the science context, and thus only applicable to objects typically measured/discussed using the Metric system.

Development of Assessment Items

- Purpose:
  - To verify and possibly refine the conception variation dimensions and typology identified in the interview study
  - To develop items for assessing the variation in the way students' understand size and scale
- Process:
  - Following the "Claim-Evidence-Task" framework
    - "Claim" and "Evidence" were derived from the specific findings of the interview study
  - Each item included a multiple-choice and a short-answer part to gain access to students' thinking/reasoning

Administration of Assessment items

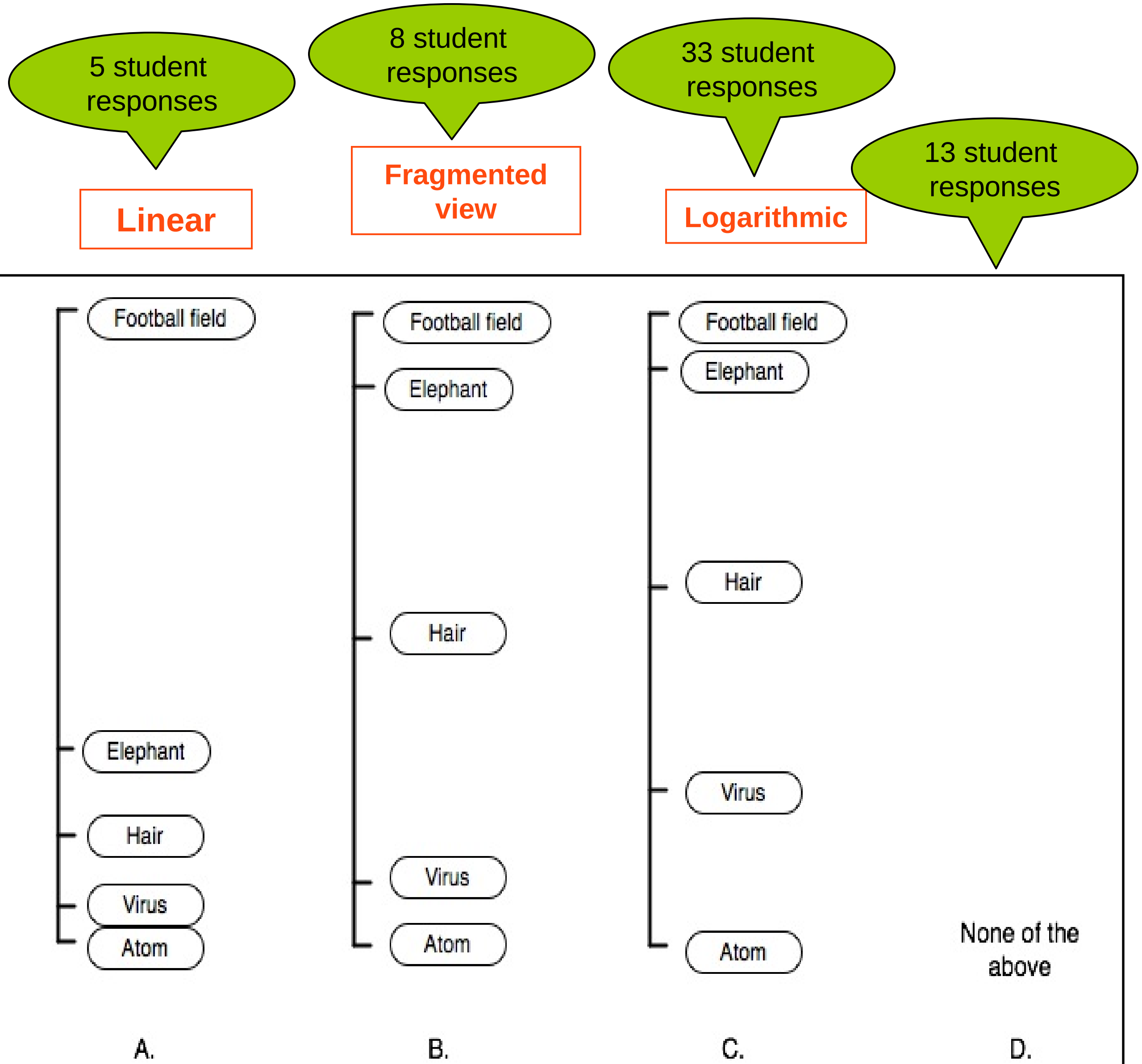
- The assessment items was recently administered to a larger population of undergraduate students
  - Items were administered at the beginning (Pre-) and the end (Post-) of the quarter
  - Selective preliminary results from 31 undergraduate students enrolled in a freshmen engineering design course are shown in the following slides.
  - Please note that since no significant differences were observed between students' pre- and post-survey responses, thus each response was treated as independent entries (59 responses).

- Preliminary analyses confirmed the conception variation dimensions identified in the interview study, as well as the possible learning barriers.

Example item 1: Scale choice and reasoning

**Note: Results shown here are based only on part of the data that have been analyzed.*

A group of engineering students were asked to create a scale that best represents the relative size differences of the following objects: the length of football field (about 91 meters), the height of an elephant (about 3 meters), a diameter of a human hair (about 0.005 meter), the diameter of a virus (about 0.0000004 meter), and the diameter of an atom (about 0.0000000001 meter). Here are some examples of what they created. Which of the following do you think is the most appropriate scale?



Example item 2: Unit confusion and Scale application

**Note: Results shown here are based only on part of the data that have been analyzed.*

24 student responses

1 student response

3 student responses

11 student responses

20 student responses

You are given the following data points: a football field is 100 yards; a dog is 2 feet tall; a hair is 1 millimeter thin; and a virus is 100 nanometers. If you were asked to create a scale that would most appropriately represent their size differences, what would you do?

A. Draw a scale with "meter" as the unit all the way through
B. Draw a scale with "foot" as the unit all the way through
C. Draw a scale with "foot" as the unit at one end, and "meter" at the other end
D. Draw a scale with "yard" as the unit at one end, and "nanometer" at the other end
E. None of the above.

Data suggested possible modifications to the typology

(subject to change)

Nature of continuum	**Category of scale(s) used**	**Sub-category of scale(s) used**
Continuous	**Dual-scale integration**	Deep-level integration (View log as ‘real’ scale)
		Surface-level integration (View log as “unreal” scale)
	Logarithmic	Deep understanding of log scale *(The original Type 1a)*
		Surface understanding of log scale *(The original Type 1b)*
	Hybrid	“Magnitude of 10” scale
		“Orders of magnitude/Proportion/Ratio” scale
		Linear scale with log elements (terminology or format) *(The original Type 2)*
	Linear	Linear scale applied to the entire size continuum
Fragmented		Linear scale applied within each “world” *(The original Type 3a)*
	“World”-based categorization	Objects grouped based on the “world” they belong to *(The original Type 3b)*

Some implications for teaching

The preliminary findings suggest that the following teaching practices may be necessary and useful in enhancing students' conception of "Size and Scale":

– Survey students' varying conceptions prior to instruction, and adjust instruction to address different levels of understanding

– Uncover and challenge students' misconceptions regarding the meaning of numerical scale(s), particularly the logarithmic scale

– Expose and rectify students' confusion over the meaning of numerical scale(s) and unit(s)

Some useful references

- Drane, D., Swarat, S., Hersam, M., Light, G., & Mason, T. (To appear in 2008). An evaluation of the efficacy and transferability of a nanoscience module. *Journal of Nano Education.*
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- Stevens, S., Sutherland, L., Schank, P., & Krajcik, J. (2007). The big ideas of nanoscience. Retrieved November 9, 2007 from http://www.hice.org/projects/nano/index.html
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