First-Year Engineering Students' Communication of Nanotechnology Size & Scale in a Design Challenge

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Abstract

While nanotechnology is a highly engaging topic for students, it entails concepts that are difficult to understand and need to be carefully considered when incorporating nanotechnology into classroom instruction. The notion of size and scale (also referred to as a "big idea" in learning nanoscale engineering & science) is a fundamental concept for understanding nanotechnology, but is also a difficult concept for students to grasp. This study was guided by the following research question: How do student teams communicate their ideas concerning size and scale concepts through their nanotechnology-based design projects? This study was conducted within a first-year engineering course at Purdue University. Students were required to create a graphical-user interface to communicate fundamental concepts of nanotechnology, including size and scale, to their peers. The final submissions of 30 teams were analyzed in this study through grounded theory. It was found that 27 teams presented content about scale and 12 teams presented content about size. Methods to scaffold students' learning of nanotechnology size and scale concepts are discussed.

I. Introduction

The mysterious world of nanoscale can stimulate young people's imagination and ignite their interest in science and technology.[1] Although students are motivated to learn about nanotechnology, the fundamental concepts are difficult for students to understand.[2] The big idea of size and scale is one of these difficult yet crucial concepts.[3,4] To avoid misconceptions and ensure deep understanding, there is a need to carefully incorporate nanotechnology into classroom instruction. This study focuses on how to incorporate concepts of nanotechnology size and scale into the classroom. There are obviously many other things to consider in nanotechnology curriculum development, such as the importance of incorporating nanotechnology applications and other nanotechnology concepts beyond size and scale,[2,5] but these ideas will not be the focus of this study.

The purpose of this study is to characterize students' demonstrated understandings of size and scale through an investigation into how first-year engineering students communicated size and scale in their nanotechnology-based design projects. The research question that guides this study is: How do student teams communicate their ideas concerning size and scale concepts through their nanotechnology-based design projects? This characterization of the students' representations of size and scale concepts will be used to inform pedagogical methods and future directions for developing theory about students' understandings of size and scale.

II. Literature Review

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Nanotechnology is "the understanding and control of matter at dimensions between approximately 1 and 100 nanometers, where unique phenomena enable novel applications. Encompassing nanoscale science, engineering, and technology, nanotechnology involves imaging, measuring, modeling, and manipulating matter at this length scale."[6]

The National Center for Learning and Teaching in Nanoscale Science and Engineering (NCLT) and the National Science Teachers Association (NSTA) discuss the "big ideas" of nanotechnology education. The concept of size and scale is one of these "big ideas".[4] Researchers that investigate the facilitation of students' transition from their undergraduate education to their industry careers through nanotechnology curriculum also explain that nanoscale concepts is one of the crucial categories of content knowledge that students need to know.[7]

Size refers to the qualitative property of an object.[8] It is the physical magnitude, extent, or bulk of the object that describes its characteristics. [1] Scale refers to the quantitative property of an object.[8] It is a measurement tool that is used by scientists to study objects and processes; scale encompasses analytical dimensions with ascending and descending steps.[9] In nanotechnology, the nanoscale is compared to a smaller scale, the atomic scale, and two larger scales, the micro and macro scales. These scales are defined in Table 1.[10]

Table 1. Definitions of Scales

<table>
<tr><th>Scale</th><th>Definition – how the scale is observed</th><th>Range (m)</th><th>Examples</th></tr>
<tr><td>Macroscale</td><td>What can be seen by the naked eye</td><td>$\geq 10^{-3}$</td><td>human, ant</td></tr>
<tr><td>Microscale</td><td>Too small to see without a light microscope</td><td>$10^{-6} – 10^{-4}$</td><td>width of human hair, red blood cell</td></tr>
<tr><td>Nanoscale</td><td rowspan="2">Too small to see without a high-powered microscope (e.g. scanning tunneling microscope – STM)</td><td>$10^{-9} – 10^{-7}$</td><td>virus, width of DNA</td></tr>
<tr><td>Atomic Scale</td><td>$\leq 10^{-10}$</td><td>atom, electron</td></tr>
</table>

The concept of size and scale is also crucial in many other fields of study (e.g. astronomy, chemistry); even though it is a fundamental concept in many fields of study, students still struggle to grasp the concepts of size and scale.[3,4,11,12] As a first step in educating undergraduates about nanotechnology, students' current understandings of size and scale needs to be investigated. Once their understandings are characterized, a pathway can be established to scaffold students' learning, and assessments can be developed to monitor students' learning.

This portion of the literature review summarizes three key studies that explored students' understandings of size and scale. Each summary reports the research method for investigating students' understandings, the pertinent findings, and limitations of the study.

Light, Swarat, Park, Drane, Tevaarwerk, and Mason (2007) explored the ways that undergraduate students understand the idea of "size and scale".[12] The 12 participants in this study were grouped based on their performance on a size and scale inventory. They were interviewed and challenged to draw out their perceptions of size and scale concepts. Participants'

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interview responses and drawings were analyzed. Students' understanding of size and scale were classified in one of two categories: (1) ordering objects and (2) scale and relative spacing of objects. Ordering objects category refers to ordering objects from largest to smallest or smallest to largest. Scale and relative spacing of objects refers to constructing drawings and explanations to make further sense of the ordered items (e.g. number of times bigger one object is as compared to another). The students in the ordering objects category exhibited a fragmented understanding of scale, because they ordered the objects (i.e. displayed understanding of size) without using quantification concepts (i.e. scale). The students in the scale and relative spacing category connected the use of scale by describing scale as a continuum to order a wide range of phenomenal sizes. This study noted the need for more investigations into students' understanding of size and scale through other probing techniques, such as analyzing homework assignments or conducting think-aloud protocols.

Delgado, Stevens, Shin, Yunker and Krajcik (2007) generated a progression of understanding to describe how students established connections of conceptions of size based on interviews conducted with 48 students from various levels of education (i.e. 7^{th} graders to undergraduates).[13] In the interviews, the students were challenged to explain various objects presented on cards to test their size and scale knowledge. The researchers developed four categories to classify the types of concepts observed: ordering objects, grouping objects, numerical size comparison of different objects, and absolute size of objects. The ordering objects category consisted of arranging objects from smallest to largest or vice versa without any quantification. The grouping of objects category consisted of creating groups to classify objects as small, medium, or large; some students classified the objects by scales (i.e. atomic, nano, micro, or macro). The numerical size comparison of different objects category refers to a demonstrated understanding of quantified comparisons of objects (i.e. number of times smaller or bigger). The absolute size of objects refers to the exact measurement of objects. The results showed that very few students' responses had fully connected the size related concepts and students' knowledge of size ranged from entirely disconnected (i.e. lack of understanding in any category) to well connected (i.e. showing understanding in all of the categories). Only six undergraduate students participated in this study, so it was noted that further investigation should be conducted with undergraduate students.

Magana, Brophy, and Bryan (2012) proposed the Framework to Characterize and Scaffold Size and Scale Cognition (FS2C).[14] The FS2C framework consists of five levels of students' understanding of size and scale. The lowest levels relate to size: qualitative categorical conception (grouping objects without reference to scales), qualitative relational conception (ordering objects), and qualitative proportional conception (difference in size between two objects compared to two other objects with an equivalent size differentiation). The highest levels relate to scale: quantitative proportional conception (number of times bigger or smaller) and quantitative absolute conception (exact measurements of objects). These five levels map, respectively, to five cognitive processes: generalization, discrimination, logical proportional reasoning, numerical proportional reasoning, and mathematical reasoning. These concepts were tested with five assessment tasks to identify understandings and difficulties exhibited by 224 first-year undergraduate students. The paper identified some difficulties that students had with size and scale concepts, including greater difficulties in understanding sub-macroscopic objects and differentiating bigger gaps between objects. Although the FS2C is an established framework

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for size and scale concepts mapped to Gagne's taxonomy of learning outcomes,[15] the validity of this framework needs to be evaluated in naturally occurring environments (i.e. the nature of size and scale concepts in students' work, not just tests created based on the framework).

These studies show that researchers have begun to characterize students' difficulties with and understandings of nanotechnology size and scale concepts. The data collection techniques included student interviews, students' documentation created during interviews, and students' responses to tests about size and scale concepts. Since these instruments and protocols were designed to elicit students' understanding of specific size and scale concepts, the analysis is limited to prompted concepts. Thus, there is a need for analysis of more open-ended, authentic student work and the development of students' understandings about size and scale. This study will address some of these gaps in the literature base by investigating authentic student work to determine students' interpretation of size and scale concepts in a more natural learning environment that does not prompt knowledge from predetermined categories.

III. Research Context

A. Setting and Participants

The participants in this study are student teams in a first-year engineering (FYE) course at Purdue University. The FYE course is a required two credit hour course that focuses on design, teaming, problem solving, and computer skills. The program consists of an average enrollment of 1650 students per semester. The structure of the course is shown in Figure 1. Each section has up to 120 students that work in teams of three to four students. The teams are assigned at the beginning of the course and work together throughout the semester inside and outside of class to complete projects and other group activities. Each of the sections has one graduate teaching assistant (GTA) and four undergraduate teaching assistants (UTAs) to help facilitate student learning in-class and assess students' works outside of class.

In Spring 2013, every section was required to implement a mathematical modeling project regarding nanotechnology measurements in the first half of the semester (i.e. the NanoRoughness Model-Eliciting Activity[16]) and a design project in the second half of the semester. The instructors for six sections agreed to incorporate the nanotechnology-based design project into their sections. This project required students to develop a Graphical User Interface (GUI) using MATLAB to teach their peers about nanotechnology for a real project partner (nanoHUB.org).[17] The student teams received a memo from the project partner that described the details of the assignment (Appendix A). The project was driven by five criteria:

1. Clearly helps peers understand the **Size & Scale** of nanotechnology (big idea #1),
2. Clearly assists peers in connecting **Size & Scale** to at least one other nanoscience big idea
3. Clearly engages peers in how criteria 1 and 2 apply to one or more engineering disciplines via model(s) or simulation(s)
4. Is highly stimulating and interactive for the targeted grade level
5. Is easy to use and operate

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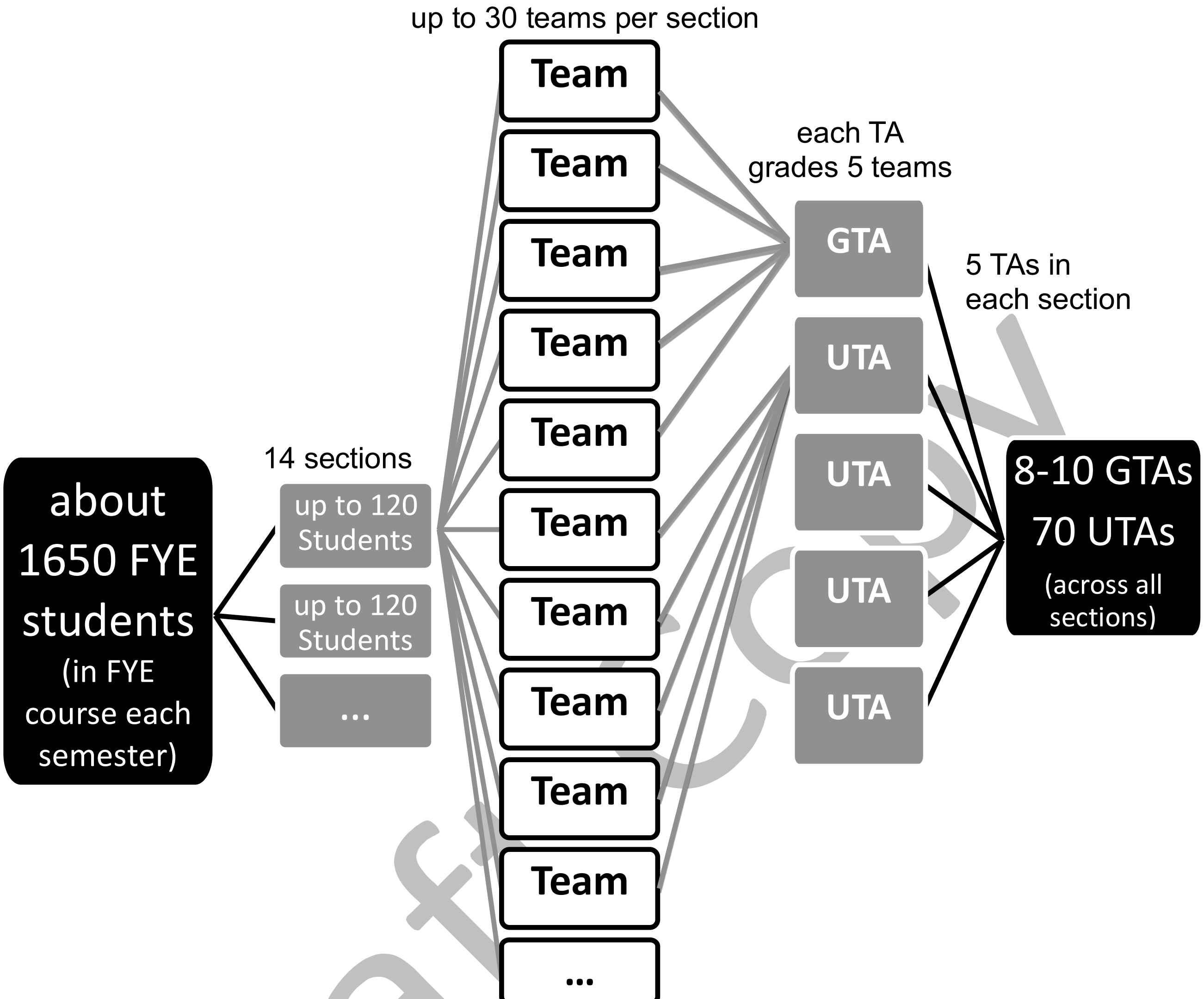

Figure 1. FYE Course Structure (Students, Teams, and Teaching Assistants)

The project was completed in nine milestones that were graded by teaching assistants (TAs) and instructors or project partner representatives (as detailed in Table 2). Each assessor assigned grades and provided written feedback. The majority of the milestones were assessed using a rubric that focused on the five established criteria (Appendix B), although some milestones focused on other aspects of the project (e.g. problem scoping and MATLAB coding). The milestones were created to help student teams successfully manage the development of their projects using an engineering design process.

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Table 2. GUI Project Milestones (Submissions)

Milestone #	Completed by:		Description of Milestone	Feedback from:		Appendix B Rubric Used
	Individual	Team		Instructor or TA	Project Partner	
1	X		**Problem-scoping:** Focus is on understanding the big picture of the project and the specific task at hand. It consists of a few questions about problem formulation, problem identification, and the deliverable.	X		
2	X		**Information Gathering:** This milestone challenges teams to better understand their target audience and evaluate the success of similar deliverables.	X		
3		X	**Idea Generation and Reduction:** Students must brainstorm potential solutions. Based on their established requirements and given criteria they evaluate their potential solutions (using a decision matrix) to select the top two ideas.	X		
4		X	**Prototype Draft 1:** Students develop a storyboard for one of their top ideas. Presentation slides and notes are used to convey potential content for each GUI to be included in the solution.	X		X
5		X	**Prototype Final:** This is an updated storyboard.		X	X
6		X	**GUI Layout:** Teams create MATLAB layouts of all their GUIs and accompanying flowcharts that explain the needed coding. This is the last submission before the coding of their actual GUIs begins.	X		X
7		X	**GUI Beta 1.0:** Teams begin coding all of the content they have planned in previous milestones.	X		
8		X	**GUI Beta 2.0:** Teams update their GUIs.		X	X
9		X	**GUI Final:** Teams finalize their GUIs and executive summary.	X		X

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B. Data Collection

All of the teams' final project submissions (Milestone 9) from one of the six sections were analyzed. This one section consisted of 30 teams. This study focused only on the teams' final submission of their GUI project and supporting MATLAB code, not the additional written documentation (i.e. executive summaries).

C. Data Analysis

Two researchers participated in the data analysis. Both researchers had previous experience with qualitative research in STEM education. Their fields of expertise are engineering education and science education. Data analysis consisted of the following steps.

1. Both researchers coded students' GUI projects independently using open coding and axial coding.[18]
2. The researchers developed coding categories based on their first round coding experience.
3. The developed categories were slightly modified to incorporate the language of the FS2C framework.[14] The names of the subcategories for the Evaluation and Comparison categories were renamed, which helped establish more detailed descriptions of the subcategories.
4. Both researchers did a second round of coding independently using the modified categories and subcategories (Table 3).
5. Finally, both researchers compared their coding results to calculate the inter-rater reliability and then came to a consensus on any discrepancies

The coding scheme consisted of three categories: Defining Nanoscale, Evaluation, and Comparison. Students' GUI content that focused on defining a nanometer or the scale range that nanotechnology encompasses was coded Defining Nanoscale. Students' GUI content that focused on an analysis of a single object was coded Evaluation. Students' GUI content in which two or more objects were compared was coded Comparison. All of these categories and their subcategories are described in Table 3. Appendix C through Appendix F provides examples of team GUIs that represent the Evaluation and Comparison coding subcategories. Where feasible, the relevant scales analyzed and compared were coded based on the scales defined in Table 1.

The inter-rater reliability score for the Defining Nanoscale category was 100%. The Cohen's un-weighted Kappa for the Evaluation and Comparison categories was 93.5%. Any score above 80% is considered high.[19] After calculating the reliability, the team reached consensus on the few items that were coded differently to obtain complete agreement for all the codes.

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Table 3. Coding Scheme Categories for Teams' GUI Projects

Categories	Subcategories	Explanations
Defining Nanoscale	Quantify Nanometer (nm)	Provides conversion of 1 nm to other units (e.g. 1 nm = $1x10^{-9}$ m; 25,400,000 nm = 1 inch)
	Nanoscale Range	Provides the range of the nanoscale (correct: 1 to 100 nm or misconception: other ranges)
Evaluation (of 1 object)	Quantitative Categorical **(Scale)**	Evaluates objects by categorizing the appropriate scale to measure it (e.g. DNA = nanoscale; fly = macroscale) *Appendix C*
	Quantitative Absolute **(Scale)**	Evaluates objects by giving a specific measurement; both numeric value and scale (e.g. width of DNA = 2.5 nm) *Appendix F*
Comparison (of 2 or more things or objects)	Qualitative Relational Only **(Size)**	Comparisons of objects that only state smaller or bigger (ordering of objects) without any quantification. (e.g. fly > blood cell > virus > DNA > nanoparticle) *Appendix D*
	Quantitative Relational Only **(Scale)**	Comparisons of numeric values that only state smaller or bigger (ordering of values) without any qualification. (e.g. 5,000,000 nm > 3 mm > 0.00007 cm) *Appendix D*
	Both Qualitative and Quantitative Relational **(Size and Scale)**	Comparisons of objects with given numeric value that only state smaller or bigger (ordering of objects and values). (e.g. virus (150 nm) > DNA (2.5 nm)) *Appendix D*
	Qualitative Proportional **(Size)**	Two objects differences in size compared through an analogy to two other objects' size differentiation (e.g. If a nanoparticle was the size of a football, a red blood cell would be the size of the football field.) *Appendix E*
	Quantitative Proportional **(Scale)**	Objects' size differentiation compared using multiplication (number of times smaller or bigger). (e.g. a red blood cell is 10,000 times bigger than a nanoparticle) *Appendix F*

IV. Results

A. Defining Nanoscale

Over half of the teams presented a definition of nanometer or a range of the nanoscale. Eighteen teams (60%) presented at least one conversion of a nanometer to another measurement (e.g. meters, centimeters, or inches). Only two teams (7%) stated that the range of nanotechnology is 1 to 100 nanometers. Three other teams (10%) mentioned a different range for the nanoscale. One team identified the range to be anything less than 100 nanometers, not acknowledging the atomic scale. Another team stated the range is 0.1 to 10 nanometers, which is off by a factor of ten. The

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third team stated, “Anything that is measured in nanometers is considered to be in the nanoscale.” Teams more commonly presented examples of scale rather than define the nanoscale.

B. Evaluation and Comparison

This portion of the results focuses on two main concepts: size and scale. Twelve teams (40%) presented content that focused on qualitative concepts (i.e. size). Twenty-seven teams (90%) incorporated content that focused on quantitative concepts (i.e. scale). Figure 2 details how all 30 teams represented size and scale within the subcategories of size and scale (Table 3). The representations of size are presented in the Qualitative: Relational and Proportional subcategories, shown in the top bars of the graph. The representations of scale are presented in the Quantitative: Absolute, Categorical, Relational, and Proportional subcategories, shown in the bottom bars of the graph.

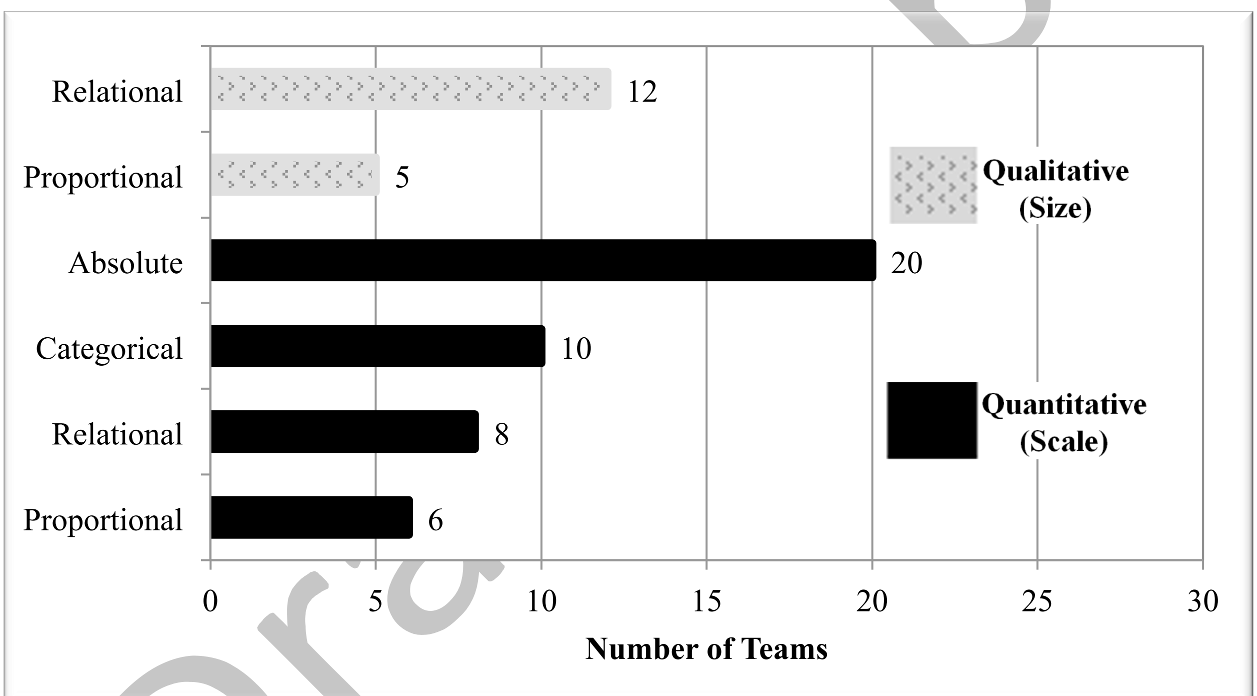

Figure 2. Teams' Size and Scale Representations

The subcategories within size and scale that are presented in the bar chart were sorted based on the frequency with which they occurred in teams’ projects (i.e. the most frequent subcategories at the top). As shown, relational comparisons were more common than proportional comparisons to describe the concepts of size and scale. The quantitative absolute was the most common representation of scale (n = 20 teams) and also the most common subcategory coded in teams’ projects.

In Table 4, the row labeled Overall shows which scales were represented in teams’ projects based on all of the content coded for the size and scale concepts (other than Qualitative Proportional). The Evaluation row details the scales represented when students presented an

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analysis of a single object. The Comparison row shows the scales represented when students compared two objects. The majority of teams discussed items that were bigger than the nanoscale; less than a quarter of the teams discussed items smaller than nanoscale. The frequency of teams that discussed the macro, micro, and nano scales was similar in the evaluation of objects and overall discussion of them, but the frequency was much less in the comparison of two objects for the microscale.

Table 4. Scales addressed in the teams' projects

	Macroscale	Microscale	Nanoscale	Atomic Scale
Evaluation of 1 object	19 teams (63%)	17 teams (57%)	18 teams (60%)	5 teams (17%)
Comparison of 2 objects	15 teams (50%)	9 teams (30%)	14 teams (47%)	5 teams (17%)
Overall any number of objects	26 teams (87%)	23 teams (77%)	24 teams (80%)	7 teams (23%)

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Figure 3 displays an example of one GUI from one team's solution that incorporates at least one item on the macro-, micro-, and nano- scale. The figure has been edited using blue boxes and text to highlight the different scales.

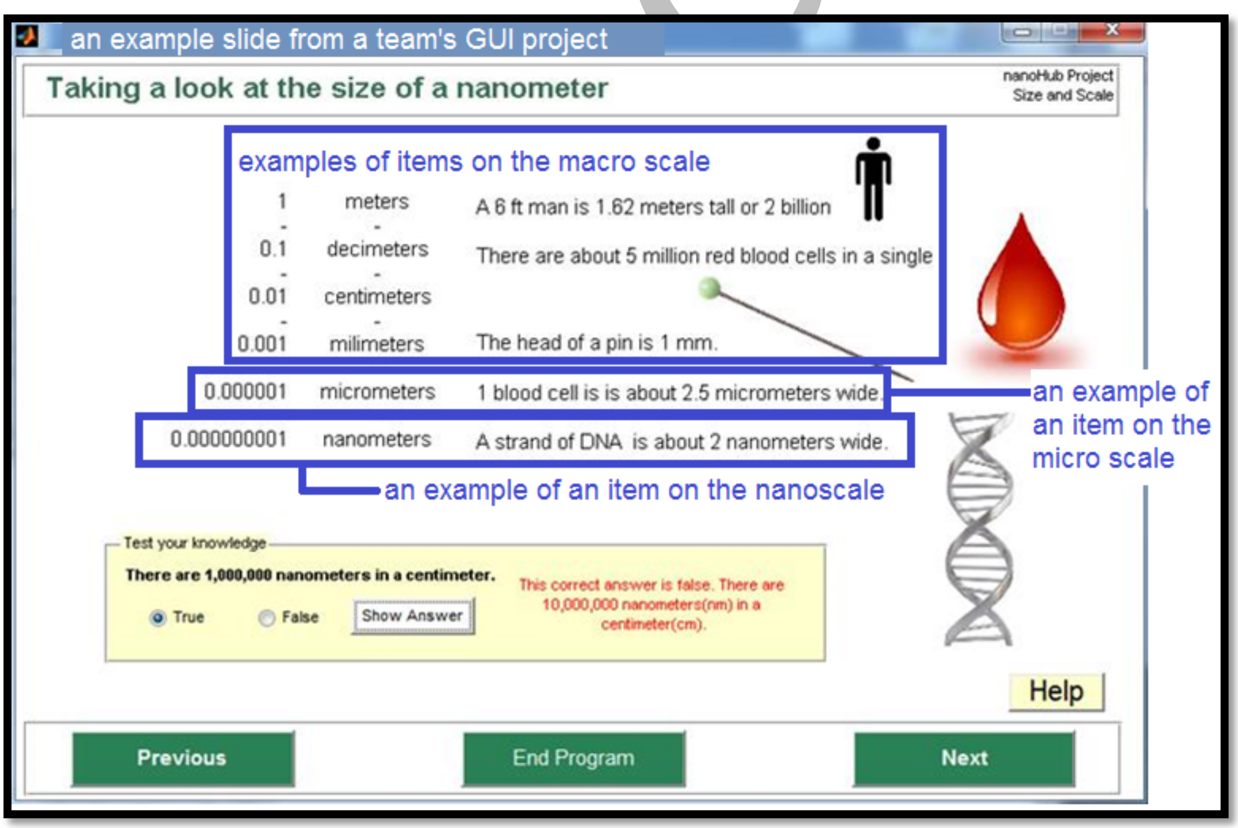

Figure 3. Screenshot of one GUI from a team's solution

(different scales are highlighted with blue boxes and text)

Table 5 shows the various scales that were compared in teams' comparisons of two things for both relational subcategories and quantitative proportional subcategory within the Comparison category. (The qualitative proportional analysis required the comparison of two objects, so it was not included.) The first cell in the table represents the number of teams (n = 4) that compared two objects that were both on the macroscale. As shown in the table, the teams most frequently compared nanoscale objects to macroscale objects (n = 7 teams).

Table 5. Number of Teams that Compared Two Objects within and across Scales

	Macro	Micro	Nano	Atomic
Macro	4			
Micro	2	1		
Nano	7	4	2	
Atomic	2	2	1	0

V. Discussion

These results show the various ways that teams communicated their ideas about size and scale concepts through their GUI solutions. The various methods of communicating size and scale concepts that were discovered in this analysis present opportunities to scaffold and assess student learning.

A. Nanotechnology Scale

The nanoscale range was hardly discussed by student teams through their GUI solutions. Those teams that did provide a range most commonly provided this information inaccurately. There appears to be many potential misconceptions concerning the definition of the nanoscale that should be further investigated and mitigated through intentional curriculum.

Student teams were required to discuss the concepts of size and scale without further direction on how to represent these ideas. Most students presented ideas about size and scale on the macro and nano scales; very few teams presented ideas on the atomic scale. The greater the difference between the size of objects, the more difficult it is for the students to comprehend the quantitative proportion between the object (i.e. how many times bigger).[14] It may be easier for students to understand the nanoscale if micro and atomic scales are further incorporated into comparisons to decrease the size difference between the compared objects. A log-scale-based relationship should be established from the macroscale to the atomic scale to help students understand the scale and range of the nanoscale. An example of a team beginning to establish this log-scale relationship can be seen in Figure 3.

B. Representations of Scale

The majority of student teams presented content that demonstrated the concept of scale, but many of them only incorporated the absolute numeric dimensions of objects (i.e. Quantitative Absolute). Magana, Brophy, and Bryan (2012) considered this the highest level of student understanding in Gagne's taxonomy (i.e. mathematical reasoning), [14] but this study found this

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concept to be the most commonly occurring representation of scale. For a student to observe an object and be able to state the absolute value of its scale, the highest level of mathematical reasoning makes sense. In the context of this study however, the task of giving an exact value of an object's scale is as easy as searching for the desired fact on the internet. For the context of this type of work, it can be assumed that this is the lowest level of students' demonstrated understanding of scale. As shown in Figure 2, proportional comparisons were the least frequent representation of scale found. Based on these results and the research team's discussion of conceptual understandings required to create the represented knowledge, we determined the less frequent representations show greater understanding of scale than the more frequent representations (i.e. Proportional > Relational > Categorical > Absolute). Magana, Brophy, and Bryan (2012) did not incorporate quantitative relational and categorical concepts in their framework, but they did include qualitative relational and categorical concepts.[14] In their ranking of these qualitative concepts, the researchers noted that the relational concept required greater understanding on Gagne's taxonomy than the categorical one. The researchers wrote that the relational concept required discrimination, whereas the categorical concept only required generalization. This established progression of presented scale concepts, gives instructors insight into students' developmental understandings of scale that can be used for scaffolding and assessing students' learning.

C. Representations of Size

Although few teams presented the concept of size in their projects, the same progression appears to occur from relational to proportional understandings. This also presents a pathway to enable instructors to scaffold and assess students' understanding. Magana, Brophy, and Bryan (2012) discussed size concepts requiring less understanding, but this study did not establish any similar kind of relation between size and scale concepts.[14] In fact, the finding that fewer teams incorporate size concepts than scale concepts may show a need to ensure students understand both size and scale concepts. In other words, it should not be assumed that students understand both size and scale, if they only demonstrate an understanding of one and not the other.

D. Representations of Size and Scale Summarized

These size and scale concepts discussed map to the categories established by Magana, Brophy, and Bryan (2012), Light, Swarat, Park, Drane, Tevaarwerk, and Mason (2007), and Delgado, Stevens, Shin, Yunker and Krajcik (2007).[12-14] Table 6 shows the coding categories developed in this paper on the far left and similar concepts discussed by these three other research groups. Some categories did not specify size or scale, so they are marked with an astrix (*) in the table. The one category that was discussed in these papers and not presented in this table is the "Qualitative Categorical Conception" discussed by Magana, Brophy, and Bryan (2012) and potentially part of the "Grouping Objects" category discussed by Delgado, Stevens, Shin, Yunker and Krajcik (2007), respectively.[13,14] If this category were to be added to Table 6, it would be incorporated above Qualitative Relational as another way to represent size. This category is not shown in the table because it was not found in the analyzed student work.

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Table 6. Size and Scale Categories Compared

Coding Categories		Light 2007[12]	Delgado 2007[13]	Magana 2012[14]
Qualitative (Size)	Relational	ordering objects*	ordering objects*	qualitative relational conception *(2. discrimination)*
	Proportional			qualitative proportional conception *(3. logical proportional reasoning)*
Quantitative (Scale)	Absolute	scale and relative spacing of objects	absolute size of objects	quantitative absolute conception *(5. mathematical reasoning)*
	Categorical		grouping objects*	
	Relational	ordering objects*	ordering objects*	
	Proportional		numerical comparison of different objects	quantitative proportional conception *(4. numerical proportional reasoning)*

VI. Conclusions

This analysis provides directions for next steps in the curriculum and instruction design for teaching size and scale, while building upon nanotechnology education research. Prior research laid the foundation for further refining a framework for scaffolding and assessing student learning about nanotechnology size and scale concepts. This paper has established some potentially new and more specific categories for characterizing students' understanding of size and scale concepts.

This revised framework should be applied to a larger data set and other contexts; this typological analysis[20] can be used to confirm the findings presented here. Another follow-up study will focus on applying this framework to earlier versions of teams' solutions to verify the progression of size and scale understandings as proposed in this paper. The proposed study will address one potential limitation of this study that the students may have been limited by their ability to code in MATLAB because some earlier iterations of this project were submitted through presentation slides. A second limitation, students' beliefs about that their peers need to learn about size and scale, remains. For an additional follow-up to the study presented here, a size and scale assessment tool has been developed based on this framework and is now being validated. Investigating students' understandings of all these types of size and scale concepts will enable further development of a learning progression for size and scale concepts.

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APPENDIX A: Memo to First-Year Engineering Teams – Introduction to the GUI Projects

To: ENGR 13200 Design Teams
From: Victoria Farnsworth, Managing Director of NCN (nanoHUB.org)
RE: nanoHUB.org Design Project Description

Let me start by telling you a little about nanoHUB.org:

> "nanoHUB.org is arguably the largest online user facility for nanoscale engineering and science modeling and simulations in the world. It is a project that is funded by the US National Science Foundation and serves over 240,000 annually. Our users are researchers from the industry, researchers, faculty members at universities worldwide, and most importantly students – at the undergraduate and graduate levels.
>
> nanoHUB.org is the place for computational nanotechnology research, education, and collaboration. nanoHUB hosts a rapidly growing collection of simulation programs for nanoscale phenomena that are accessed through your web browser. In addition there are online presentations, courses, learning modules, podcasts, animations, teaching materials, and more to help you learn about the simulation programs and about nanotechnology. nanoHUB supports collaboration via workspaces and user groups.
>
> Our mission is to support the National Nanotechnology Initiative (NNI) by creating and operating an ever-evolving cyber-platform for sharing simulation and education resources. Our mission is embodied in nanoHUB.org and driven by pioneering research, education, outreach, and support for nanotechnology community formation and growth."

Nanotechnology is increasingly an important aspect of numerous engineering and science disciplines. Profs. Mark Lundstrom and Ashraf Alam – two of the top scientists working in nanotechnology today and who have contributed numerous materials to nanoHUB.org – point out that "Nanotechnology is not a field of engineering - it is a set of concepts, tools, and techniques that has become important in all engineering disciplines." And – "Students should realize that whether they become electrical, computer, materials, mechanical, etc. engineers, nanotechnology will be important to them and that the key concepts cut across all disciplines in engineering and science."

The project you are going to work on is derived from the above perspective. Students think that the study of nanotechnology begins at the advanced levels of undergraduate study. However, the foundations of what is needed to be successful in understanding concepts related to nanotechnology can and should be laid earlier in ones undergraduate program. A solid foundation can prepare undergraduates to be active participants in the development of nanotechnologies through programs like SURF – Summer Undergraduate Research Fellowships (https://engineering.purdue.edu/Engr/Research/SURF). The nanoHUB team believes that your team can help us introduce your peers to the big ideas in nanoscience by developing educational tools that enable visualization and exploration.

The nanoHUB team is therefore requesting that your team produce an interactive and educational MATLAB-based program that engages peers (first-year and sophomore engineering students) in learning how **Size & Scale** and a least one other big idea of nanoscience apply to one or more engineering disciplines via model(s) or simulation(s).

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The other big ideas in nanoscience (http://www.mcrel.org/nanoteach/pdfs/big_ideas.pdf) from which your team can select are:

2. **Structure of Matter:** Atoms make up matter. Atoms are in constant motion and they interact with each other to make molecules. Atoms, molecules and/or nanoscale structures interact with each other to form nanoscale assemblies.
3. **Size-Dependent Properties:** Properties of matter can change with scale. Unexpected properties at the atomic scale can lead to new and desirable functionality.
4. **Forces & Interactions:** The relative impact of forces changes with scale. Electrical forces tends to dominate the interactions between objects at the nanoscale.
5. **Self-Assembly:** Organized structures can spontaneously assemble under specific conditions.

To help your team understand nanotechnology a bit better, create an account on nanoHUB.org and look for resources that introduce you and your team to nanotechnology.

A successful solution to the nanoHUB problem must meet ***ALL*** of the following ***criteria***:

6. Clearly helps peers understand the **Size & Scale** of nanotechnology (big idea #1),
7. Clearly assists peers in connecting **Size & Scale** to at least one other nanoscience big idea, and
8. Clearly engages peers in how 1. & 2. apply to one or more engineering disciplines via model(s) or simulation(s)
9. Is highly stimulating and interactive for the targeted grade level
10. Is easy to use and operate

To maximize the impact of your team's effort, various nanoHUB partners, in addition to your instructors, will provide feedback on your work at appropriate times. The following tentative deadlines have been negotiated with your instructors:

1. Project scoping will prepare you and your team to ask nanoHUB representatives questions about the project (February 14/15th)
2. A user-profile will help you understand peers preparation for understanding the big ideas of nanoscience and nanotechnology applications, and evaluation of existing interactive, educational tools will help you understand the possibilities and expectations for your team's solution (February 21st/22nd)
3. A memo to nanoHUB will summarize results from concept generation and reduction (February 28th/March 1st)
4. A preliminary proposal for your team's solution will be submitted to the ENGR 132 instructional team for feedback (March 7/8th)
5. A final proposal will be sent to nanoHUB for feedback (March 28/29th)
6. A draft of the graphical-user-interface (GUI) and complete flowcharts for all functions needed to achieve the criteria will be submitted to the ENGR 132 instructional team for feedback (April 11/12th)
7. A working (beta 1.0 version) program will be demonstrated (April 18/19th)
8. Your team's "near" final program (beta 2.0 version) will be demonstrated to nanoHUB partners (April 23/24rd)
9. A demonstration of your team's final program will be given to the ENGR 132 instructional team. In addition, an executive summary that describes your team's solution will be submitted (along with a copy of your final MATLAB program) to nanoHUB (April 25/26th)

I understand that your instructional team will handle posting of your program if your program is properly uploaded to your Blackboard course management software.

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Your ENGR 13200 instructors have allowed us to work with you and your team because they believe this project will allow you to demonstrate that you have understood the material included in ENGR 13200.

They also believe that this project will allow you to bring together these course objectives:

- Develop a logical problem solving process which includes sequential structures, conditional structures, and repetition structures for fundamental engineering problems,
- Solve fundamental engineering problems using computer tools,
- Employ design and problem processes in modeling, problem solving and design work,
- Work effectively and ethically as a member of a technical team,
- Develop a work ethic appropriate for the engineering profession,
- Reflect on personal and team performance to achieve continuous improvement, and
- Demonstrate an ability to engage in continuing professional development.

The time your instructors have designated for this project is short, so your team will need to be focused.

I wish you the best of luck and look forward to seeing your creative designs.

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APPENDIX B: Rubric to Assess First-Year Engineering GUI Projects

CRITERIA EVALUATION				
Criterion 1: Clearly helps peers understand the Size & Scale of nanotechnology (big idea #1)				
☐ **Very Poor (0)** • Missing Size & Scale idea • Will cause mis-understanding(s) of Size & Scale	☐ **Poor (15)** • Potential to create mis-understanding(s) of Size & Scale	☐ **Mediocre (30)** • Weak connection to Size & Scale • Too difficult or easy for peers	☐ **Good (40)** • Text or image only connection to Size & Scale • At an appropriate level for peers	☐ **Excellent (50)** • Engages peers in learning about Size & Scale with an appropriate amount of challenge
Comments:				
Criterion 2: Clearly assists peers in connecting Size & Scale to at least one other nanoscience big idea				
☐ **Very Poor (0)** • No big nanoscience idea • Will cause mis-understanding(s) of big nanoscience idea(s)	☐ **Poor (15)** • Potential to create mis-understanding(s) of big nanoscience idea(s)	☐ **Mediocre (30)** • Weak connection to big nanoscience idea(s) • Too difficult or easy for peers	☐ **Good (40)** • Text or image only connection to big nanoscience idea(s) • At an appropriate level for peers	☐ **Excellent (50)** • Engages peers in learning about big nanoscience idea(s) with an appropriate amount of challenge
Comments:				
Criterion 3: Clearly engages peers in how 1. & 2. apply to one or more engineering disciplines via model(s) or simulation(s)				
☐ **Very Poor (0)** • No engineering discipline application	☐ **Poor (15)** • Potential to create mis-understanding(s) of connection(s) between big nanoscience idea(s) and engineering discipline(s)	☐ **Mediocre (30)** • Weak connection between big nanoscience idea(s) and engineering discipline(s) • Too difficult or easy for peers	☐ **Good (40)** • Appropriate connections between idea(s) and engineering discipline(s) • Few interactions with model(s) and simulation(s)	☐ **Excellent (50)** • Engages peers in multiple interactions with model(s) and simulation(s)
Comments:				

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Criterion 4: Is highly stimulating and interactive for the targeted audience				
☐ **Very Poor (0)**	☐ **Poor (15)**	☐ **Mediocre (30)**	☐ **Good (40)**	☐ **Excellent (50)**
• No goal • 1-way communication • No choice	• Goal is confusing • 2-way communication is difficult to understand • Consistently high memory load	• Goal drifts • Limited 2-way communication • Limited choice • Many instances of high memory load • Limited visual appeal	• Goal is clear & maintained • Appropriate amount of 2-way communication • Some user choice • Few instances of high memory load • Visual appealing	• Goal is interesting • 2-way communication is meaningful • User choice is meaningful • Keeps memory load to a minimum • Visually attractive
Comments:				

Criterion 5: Is easy to use and operate				
☐ **Very Poor (0)**	☐ **Poor (15)**	☐ **Mediocre (30)**	☐ **Good (40)**	☐ **Excellent (50)**
• Organization is overall very confusing • Navigation forward, backward, or to exit is missing • Many dead ends	• No errors are prevented • Screens contain irrelevant information (cluttered) • No help is provided to move forward and correct errors • Organization is difficult to follow within or between screens • Navigation forward, backward, or to exit is missing in some places • Some dead ends	• Language is too difficult for user • Many screens contain irrelevant information (cluttered) • Few user errors are prevented • Limited help provided to move forward and correct errors • Inconsistent use of conventions (e.g., for navigation)	• Language is difficult for user in some locations • Some screens contain irrelevant information (mostly uncluttered) • Some user errors are prevented • Some help is provided to move forward and correct errors • Some inconsistent use of conventions	• Language is appropriate for user throughout • Screens contain only relevant information (uncluttered) • User errors are prevented throughout • Help is provided to move forward and correct errors • Organization is clear throughout • Conventions consistent throughout
Comments:				
Additional Comments:				
			TOTAL POINTS (out of 250)	

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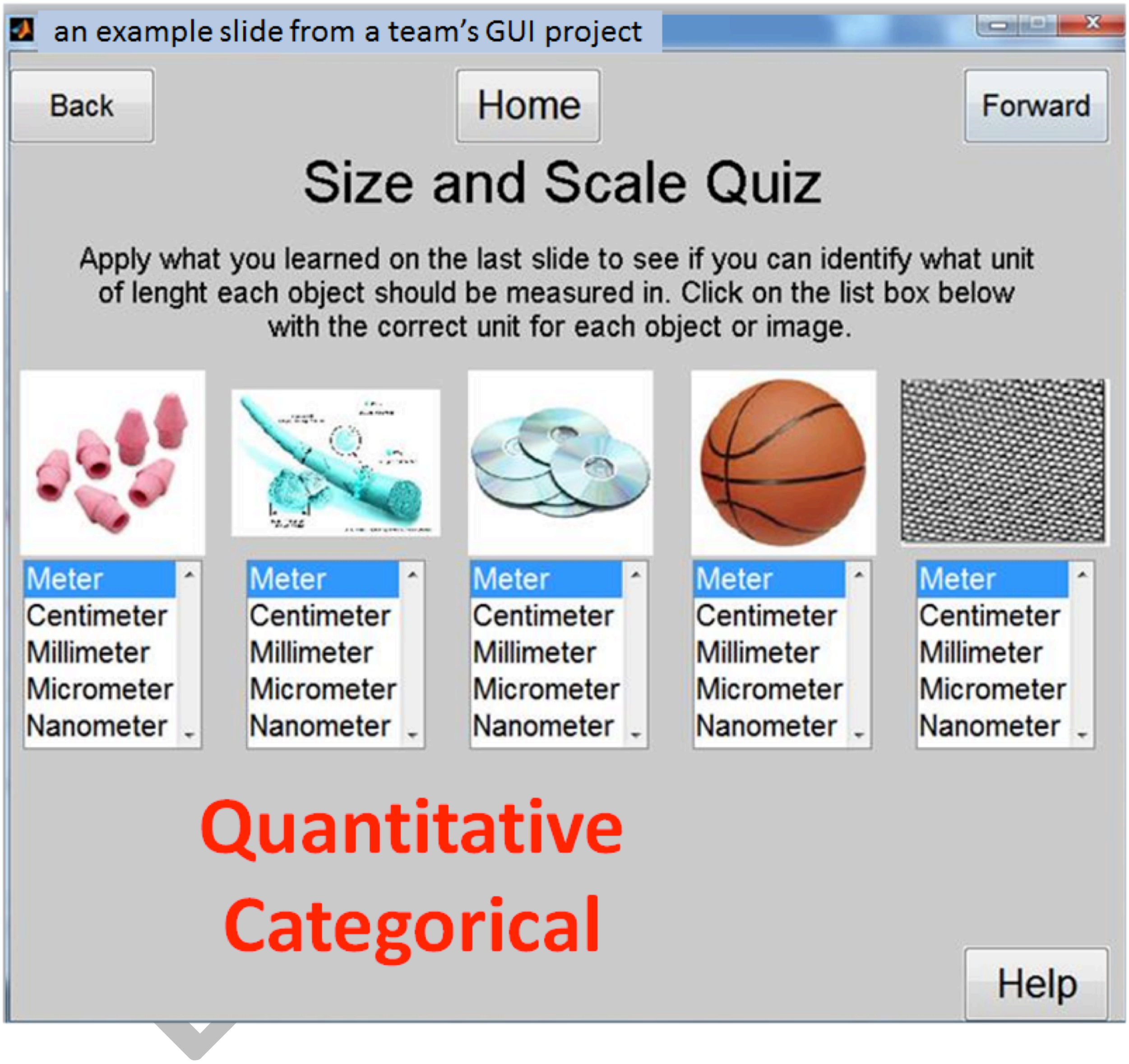
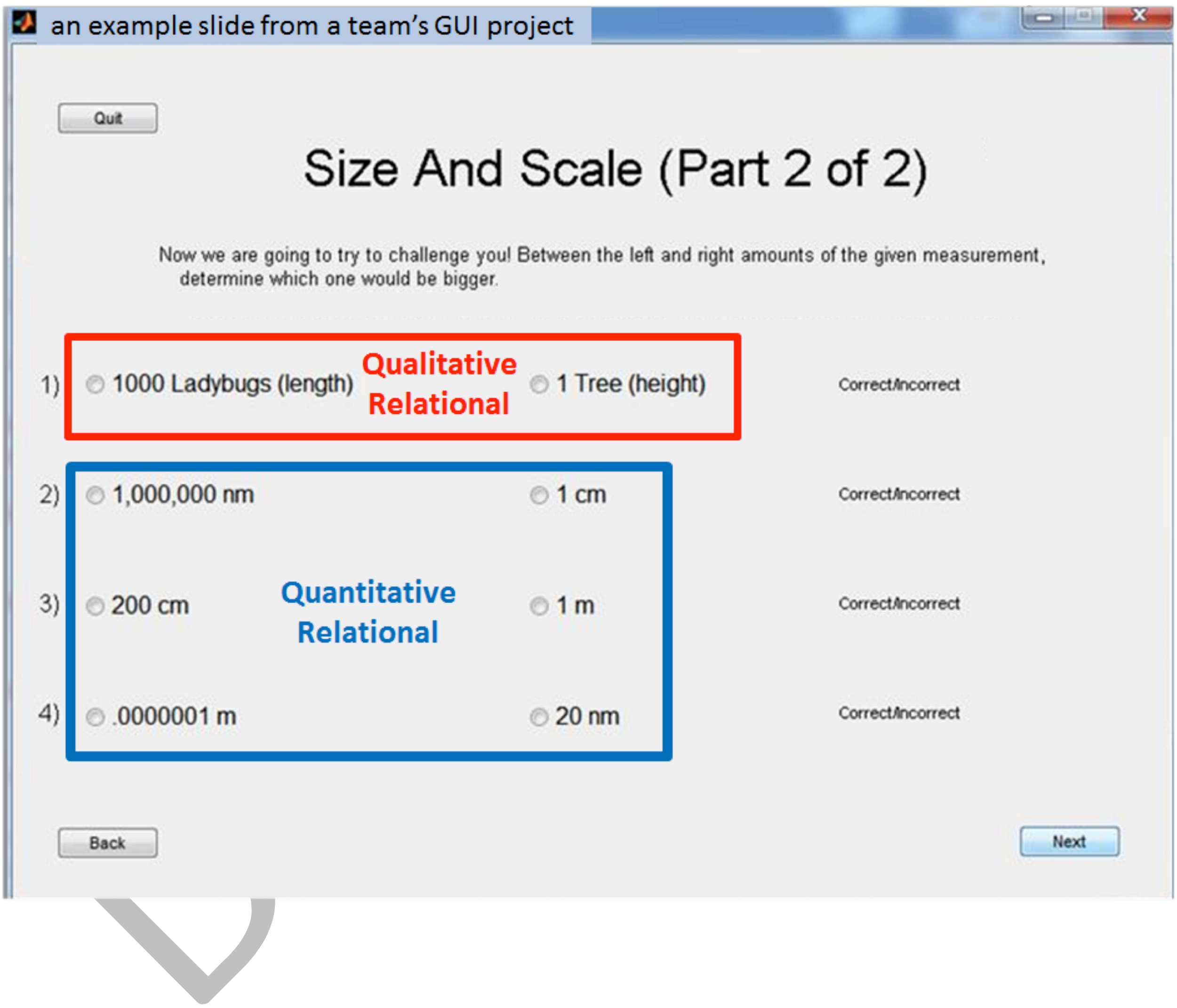
APPENDIX C: Example GUI – Quantitative Categorical (Scale)

The student team requires the user to select the appropriate unit of measurement to measure the given objects. For example, the strand of hair (shown in the second image from the left) should be measured in micrometers and the nanoparticles (shown in the far right image) should be measured in nanometers. There are specific quantitative categories, but there are not absolute values; this makes this an example of quantitative categorical (scale).



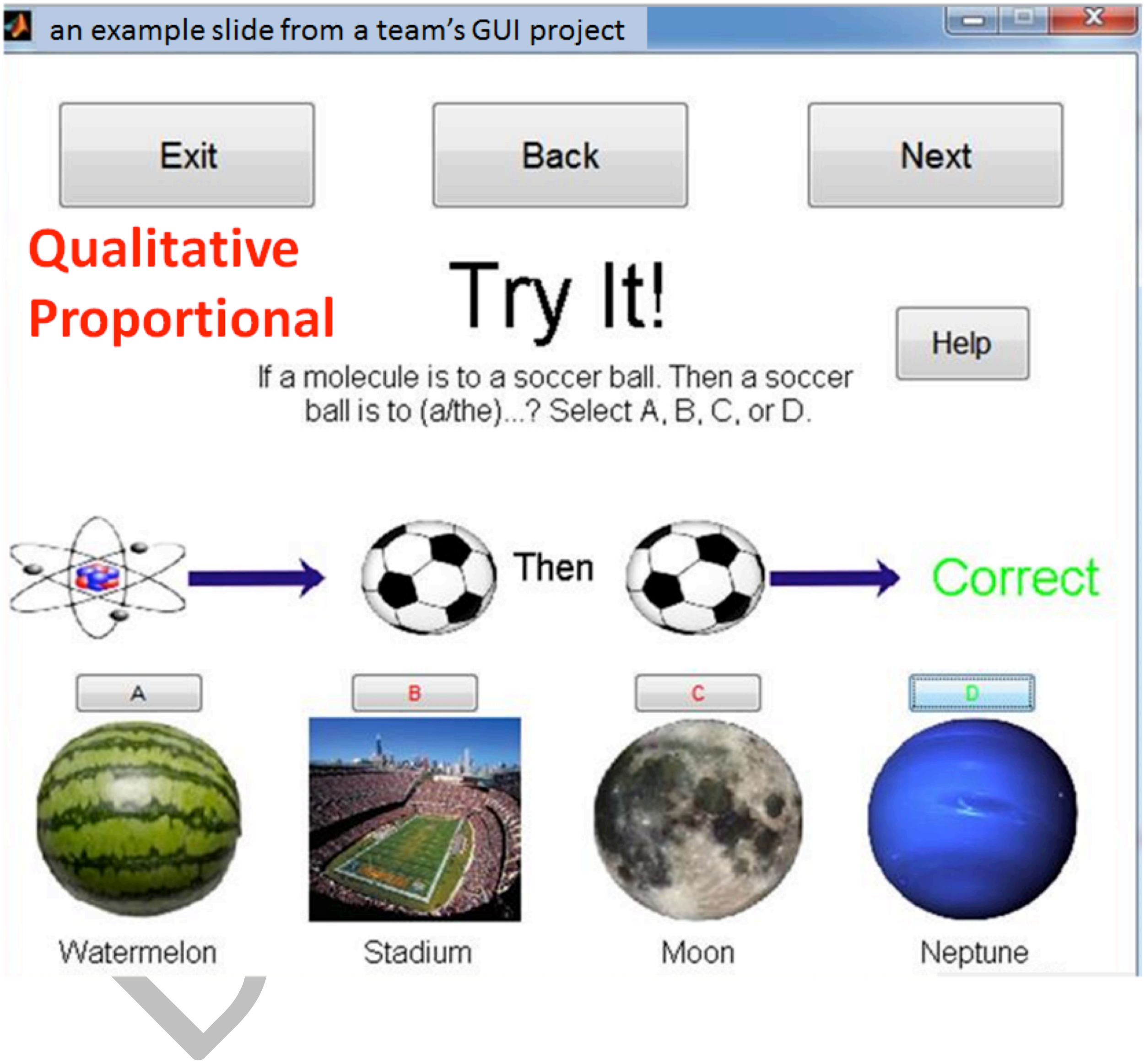
APPENDIX D: Example GUI – Qualitative Relational (Size) and Quantitative Relational (Scale)

The student team requires the user to make four comparisons of two objects. The first comparison is of a tree and 1000 ladybugs. These objects do not have an absolute value, so they are purely qualitative. This is an example of qualitative relational (size). The last three comparisons are of two absolute values that are not associated with an object, so they are purely quantitative. These are examples of quantitative relational (scale). An example of both qualitative and quantitative relational (size and scale) would be the comparison of two objects (e.g. ladybugs and trees) that are assigned an absolute value (e.g. 1,000,000 nm and 1 cm).



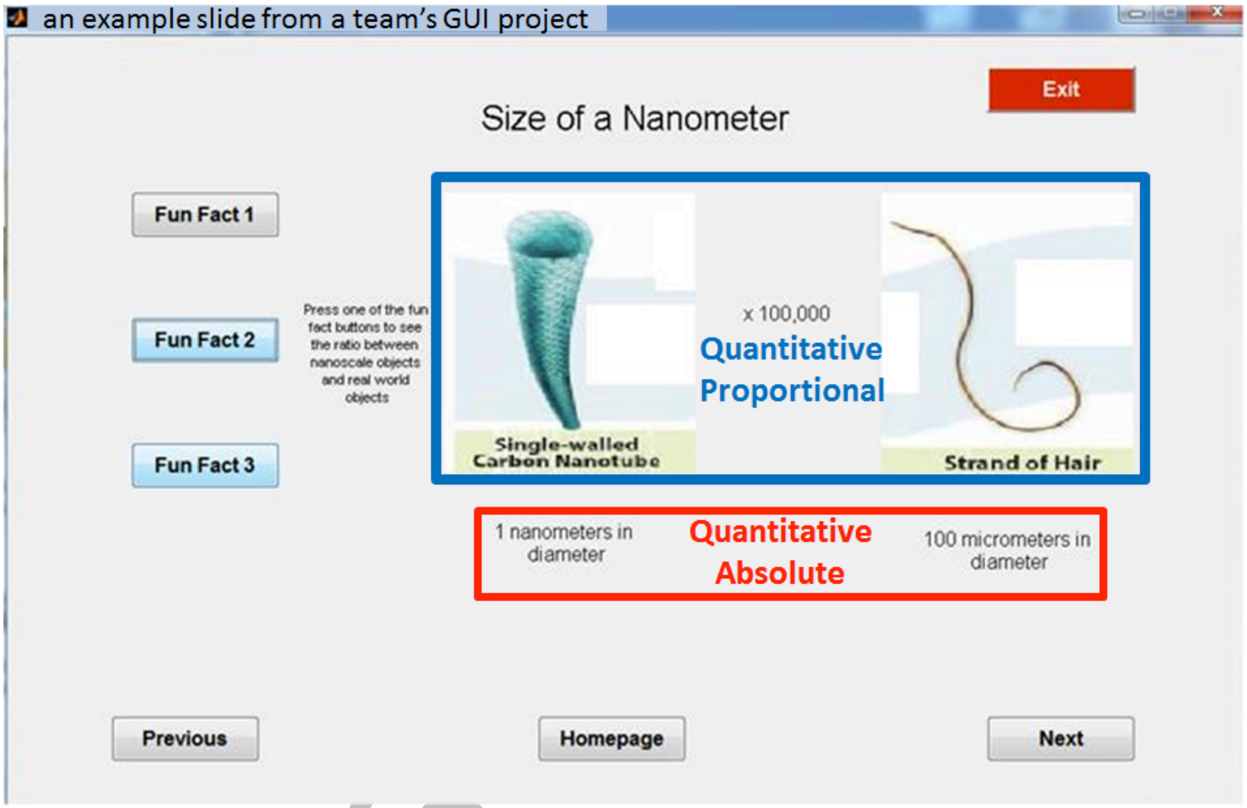
APPENDIX E: Example GUI – Qualitative Proportional (Size)

The student team requires the user to select the object that would accurately complete this statement, "If a molecule is to a soccer ball. Then a soccer ball is to (a/the)…" This is an example of qualitative proportional (size). The team is comparing objects in manner that is more than a simple relational statement about which is bigger, but is not as detailed as a quantitative proportional statement about specifically how many times bigger.



APPENDIX F: Example GUI – Quantitative Proportional and Absolute (Scale)

The student team informs the user of two factual pieces of information: (1) exactly how many times bigger one object is than another (Quantitative Proportional – Scale) and (2) exactly how big each object is (Quantitative Absolute – Scale). This team presented a calculation of how many times bigger a strand of hair is than a single-walled carbon nanotube (Quantitative Proportional – Scale). The team also stated the exact measurements of the single-walled carbon nanotube and the strand of hair (Quantitative Absolute – Scale).



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