December 2012

The Measure and Instruction of Scale in Introductory Chemistry

Karrie Linn Gerlach
University of Wisconsin-Milwaukee

THE MEASURE AND INSTRUCTION OF SCALE
IN INTRODUCTORY CHEMISTRY

by

Karrie L. Gerlach

A Thesis Submitted in

Partial Fulfillment of the

Requirements of the Degree of

Master of Science

in Chemistry

at

The University of Wisconsin-Milwaukee

December 2012

ABSTRACT

THE MEASURE AND INSTRUCTION OF SCALE IN INTRODUCTORY CHEMISTRY

by

Karrie L. Gerlach

The University of Wisconsin-Milwaukee, 2012
Under the Supervision of Dr. Kristen Murphy

As a student, it is fundamental to comprehend how small an atom or molecule is in order to truly understand how the world works. The American Association for the Advancement of Science (AAAS) has determined that scale is a critical theme that pervades through all areas of science and is critical to a deep understanding. This project determined that students, which are more proficient with scale and moving between the macroscopic and particle worlds, were better performers in chemistry classes. Interviews were used to determine what the students understood and what common misconceptions were present. These lead to the development of two in-class lessons where the students interacted with live and remote instrumentation. A need to determine the proficiency of scale understanding on the classroom level lead to the development of two assessments which, when combined, determine a student's scale literacy. The scale literacy was determined to be a better predictor of student success in introductory chemistry classes than other currently used tests. To develop their scale literacy further, supplementary instruction using interactive activities were created and measured for effectiveness. Scale was determined to be a critical piece to a student's fundamental understanding however

more needs to be done to completely understand the continuum of scale development from novice to expert.

TABLE OF CONTENTS

Chapter	Title	Page
	Abstract	ii
	List of Figures	vii
	List of Tables	ix
1	Introduction	1
2	Interviews	
	2.1 Introduction	8
	2.2 Literature Review (Previous Research)	9
	2.2.2 Research Questions	12
	2.3 Methods	12
	2.3.1 Overview	12
	2.3.2 Scale Interviews	13
	2.3.3 Unitizing/Anchoring Interviews	15
	2.4 Results	17
	2.4.1 Scale Interviews	17
	2.4.2 Unitizing/Anchoring Interviews	26
	2.5 Discussion	31
	2.6 Conclusion	32
	2.7 References	34
3	In Class Modules	
	3.1 Introduction	35
	3.2 Literature Review (Previous Research)	36
	3.3 Methods	38
	3.3.1 Overview	38
	3.3.2 Module Development	39
	3.4 Results	41
	3.5 Discussion	45
	3.6 Conclusion	45
	3.7 References	46
4	Assessments	
	4.1 Introduction	47
	4.2 Literature Review (Previous Research)	48
	4.3 Methods	51
	4.3.1 Overview	51
	4.3.2 Assessment Development	51
	4.4 Results	
	4.4.1 Scale Literacy Skills Test (SLST)	54

4.4.2 Scale Concept Inventory (SCI) 57
4.4.3 Scale Literacy Score (SLS) 58
4.5 Discussion 60
4.6 Conclusion 61
4.7 References 62

5 Supplemental Instruction
5.1 Introduction 63
5.2 Methods 67
5.2.1 Overview 67
5.2.2 Development of the Instructional Materials 68
5.3 Results 73
5.4 Discussion 79
5.5 Conclusion 80
5.6 References 81

6 Conclusion 82

7 Appendices
A Interviews 84
B Assessments 108
C In Class Modules 114
D Supplemental Instruction 141

LIST OF FIGURES

Figure	Description	Page
1.1	Johnstone's Triangle	3
1.2	Piaget's Cognitive Development Stages	4
2.1	Unitizing interview example card	15
2.2	Unitizing interview comparison drawing example	16
2.3	Results of Phase 1 scale interviews – Activity 2	19
2.4	Results of Activity 3 –rank ordering	21
2.5	Example of student response and grading on Activity 4 in scale interviews.	22
2.6	Results of phase 1, activity 4 – average relative item placement	24
2.7	Absolute scaling results of objects.	25
2.8	Average of total magnitudes off for items by group.	27
2.9	Activity 2 (How much Bigger?) results of average magnitude errors for each item.	27
2.10	Interview examples of comparison drawings.	28
3.1	Results of phase 1 scale and macro/particle assessment questions during Fall 2008.	42
3.2	Results of phase 2 scale and macro/particle assessment questions during Spring 2009.	42
3.3	Examination of scale performance vs. math placement exam performance.	43
3.4	Examination of scale performance vs. both math and chemistry placement exam performance.	43
3.5	Macro/Particle (Spring 2009) assessment questions categories of conceptual and algorithmic.	44
4.1	Flowchart of assessment development	53
4.2	Performance of each group on Trajectory of Scale specific items.	56
4.3	Comparison of novice and experts groups in Jones' Trajectory skills.	56
5.1	Ebbinghaus' Forgetting Curve	64
5.2	Example of how Ebbinghaus' Forgetting Curve changes with distributed practice	64
5.3	Dale's Cone of Learning	65
5.4	Johnstone's Information Processing Model based on Piaget's theories	65

5.5	Question organization	68
5.6	Online supplemental instruction quiz pathways and conditional release requirements.	69
5.7	Results of supplemental instruction and scale literacy	73
5.8	Comparison of student performance group versus number of attempts per activity	74
5.9	D2L Supplemental Instruction: Collaborative Learning Groups vs. Individual Learning	75
5.10	Treatment group comparison of initial and final questions.	76
5.11	Initial to final change comparison for treatment	76
5.12	Results for all of the students on initial and final scale literacy	76
5.13	Survey Results	78

LIST OF TABLES

Table	Description	Page
2.1	Descriptions and sizes of interview objects	13
2.2	Student performance: interview activities 2 & 3	18
2.3	Results of comparative drawings: visible/visible & visible/non-visible	29
2.4	Results of comparative drawings, non-visible/non-visible	30
4.1	Fall 2009 results of SLST item analysis	54
4.2	Analysis of SCI	57
4.3	Common Predictors of General Chemistry I Performance	59
4.4	Common Predictors of General Chemistry I Performance by instructor	59
5.1	Jones Trajectory of Scale Concept Development	70

Chapter 1:

Introduction

For many students, chemistry is one of the most difficult classes they will encounter during their education, and some of them deliberately steer away from the discipline altogether. Students tend to say that "it is too hard" or the content "is too confusing". Even for strong science students, many concepts in chemistry can be quite challenging. For those of us that have chosen chemistry as a career, we also had our content area bane; however, we were able to come to some understanding of it and move forward. This, however, isn't true for many students. This begs the question: What makes individuals who end up in chemistry-related careers different learners than those students who veer away? Is it the sole responsibility of the content itself, or is it a lack of some fundamental skill that was never developed during their years of schooling?

In 1985, the American Association for the Advancement of Science (AAAS) introduced a monumental project called Project 2061[2], which had the goal to advance science literacy among all Americans. To date, this project has presented the science content of what all Americans should know and provides the research and also develops tools for educators, researchers, and policymakers so that they can provide the best education to teach this content. The long-term goal is to provide a large and lasting positive impact on the public educational system in the United States. Project 2061 has provided this information to this point through several publications: *Science for All Americans*[3], *Benchmarks for Science Literacy* [4], and the *Atlas of Science Literacy* [5].

In this project, there are fundamental themes that pervade throughout all fields of science: systems, models, constancy and change, and scale. These themes include skills that scientists, when observing and creating explanations of everyday phenomena, are fundamental and critical for understanding, predicting, and communicating these explanations. The National Science Education Standards [6] mention the importance of scale, however, it is often overlooked when a state's standards are written and these certainly have not stressed the need for this to be incorporated as a common theme. These themes also may seem like something that would normally get taught along with the content and/or students would just develop skills in these over time, however, this assumption may be an oversight and without direct modeling and teaching of these themes, students may develop the associated skills incorrectly or they may not develop these skills at all. Recently the National Research Council (NRC) released a report titled *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas*[7] that utilizes the AAAS's Project 2061 and identifies key scientific ideas and practices all students should learn by the end of high school. This report includes "Scale, proportion, and reasoning", which is the primary focus of our study, as one of its seven crosscutting concepts.

In chemistry, the understanding of the particulate nature of matter is fundamental to understanding the scientific concepts. The particulate nature of matter is certainly taught in chemistry courses, however, the important link between this model and the macroscopic phenomena that are observed may not be taught. Additionally, the bridge between these realms most certainly includes the understanding of the size of atoms and molecules. Johnstone[8] modeled the components for the three representations in physical science (Figure 1.1) as an equilateral triangle with the teaching areas on each apex. Any point within the triangle is meant to represent the ratio of time given to each topic. It could be argued that traditionally the majority of chemistry classes spend the largest amount of time working in the symbolic and mathematical area and little time is given to the macroscopic and molecular or particle worlds. In other words, less time may be allocated to the particulate nature of matter and bridging this description to the macroscopic phenomena that are observed. The bridge between these macroscopic and particle representations includes concepts related to spatial scale. By using this model, a shift can occur towards the center of the triangle so that equal times are dedicated to each concept area. In a different study by the foremost researcher studying scale, Gail Jones with Amy Taylor[9] found that experienced individuals were able to move more fluidly between scales with the use of a variety of reference objects for anchoring their mental jumps into new realms. These individuals have developed these tools from their experiences. Linking these studies back to the chemistry classroom, to best utilize Johnstone's model and the findings of Jones and Taylor, strong support emerges for the necessity to incorporate themes related to scale as a connection for the novices to move between the macroscopic and particle worlds.

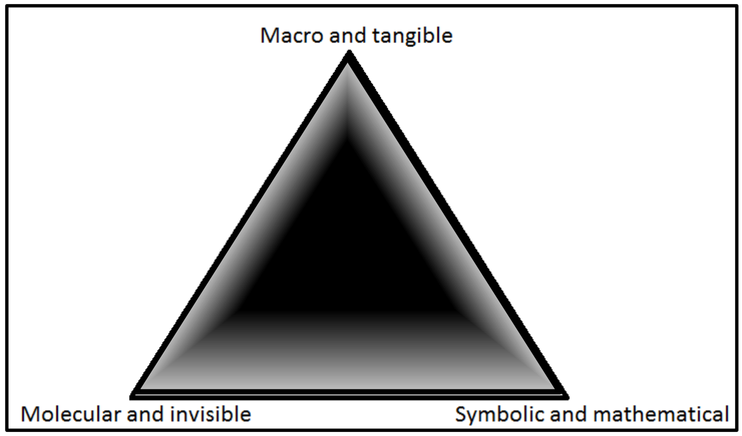


Figure 1.1 - The aspects of representation in the physical sciences.

There is an old saying in teaching that says “we teach how we were taught” which means that we rely on our own experiences as a student to facilitate a classroom lesson. Chemistry is often taught solely by looking at symbols and by solving equations. However, we also understand that students have daily encounters with scientific phenomena, and without guidance, students will often explain these phenomena in counter-intuitive ways because they rely heavily on their previous knowledge and their macroscopic experiences. For example, a student would typically describe the surface of a table as solid and therefore matter must be continuous, without holes or space. If we aren’t spending time connecting those experiences, it is no wonder students have a lack of understanding of the links between what is done in class and how the world really works around them.

In a study by Brosnan and Reynolds[10], students aged 11 to 17 explained everyday phenomena during interviews with regards to their particulate understanding. They concluded that based on the student’s written and verbal responses, insight was provided into the students’ theoretical level of understanding of chemical phenomena at the macroscopic and particle levels. This allowed the researchers to classify the knowledge level of the students with respect to macroscopic and particle understanding. Jean Piaget described the ages where cognitive changes occur which can be seen in Figure 1.2. When aligning the study with Piaget’s cognitive development stages,

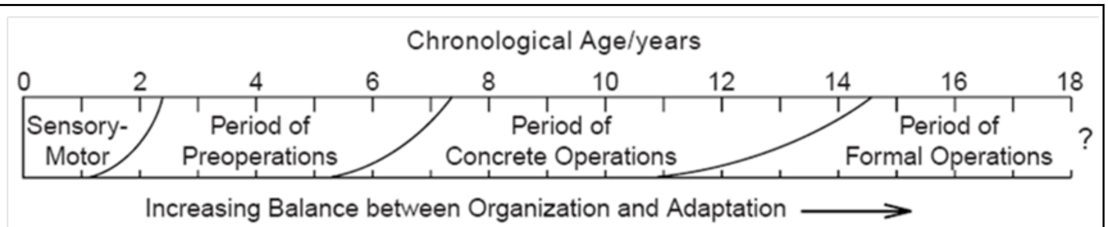


Figure 1.2 – Piagetian cognitive development stages.[1]

younger students were mostly within the concrete 'macroscopic' classification and the older students were classified in the more abstract 'within particle' classification. A study done by Gabel[11] in the early 1990's, showed that by providing only 45 opportunities throughout the year utilizing particulate nature of matter practice and by using the GALT (Group Assessment of Logical Thinking)[12] as a covariate measure, statistically significant improvements in the students' scores were seen on the three levels: macroscopic, particle, and sensory.

For my project, we began by assessing the scale perceptions and conceptions of our students with one-on-one interviews. This knowledge was the foundation for specific areas of need with regards to scale and provided some ideas on how to address this need. We then developed in-class modules that could be used in large classroom environments. Two complimentary class-wide assessments were developed and tested based on the literature and the one-on-one interviews. These were utilized to measure the initial scale literacy of students in introductory chemistry courses as well as in a pre- and post-testing method to determine the degree to which any interventions were changing the scale literacy of the students. Finally, we developed performance appropriate supplementary instruction for students outside of the classroom.

Our fundamental questions for this project regarding scale were:

1. What is the scale literacy of students in introductory college chemistry courses?

2. Is scale literacy correlated with how students perform in general chemistry courses supplementary and if so, could scale literacy be used as a predictor of success?
3. How would active recall instruction impact the scale literacy of students?

By gaining a better understanding of the impact scale on student success, and therefore, determining where our students are within the understanding continuum of scale, will provide the starting point for potential curriculum reform in chemistry. This will provide not only better learning opportunities within the classroom but also contribute to the improvement of a key component of a student's science literacy.

REFERENCES

[1] D. M. Bunce, *Journal of Chemical Education* **2001**, *78*, 1107.
[2] AAAS in *Project 2061*, *Vol.*
[3] F. J. Rutherford and A. Ahlgren, *Science for all Americans*, Oxford University Press, **1990**, p.
[4] *Benchmarks for Science Literacy*, Oxford University Press, **1994**, p.
[5] AAAS, *Atlas of science literacy*, American Association for the Advancement of Science : National Science Teachers Association, Washington, DC, **2001**, p.
[6] N. C. o. S. E. Standards, Assessment and N. R. Council, *National Science Education Standards*, The National Academies Press, **1996**, p.
[7] C. o. C. F. f. t. N. K.-S. E. Standards and N. R. Council in *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas*, *Vol.* Eds.: Q. Helen, S. Heidi and K. Thomas), The National Academies Press, **2012**.
[8] A. H. Johnstone, *Journal of Chemical Education* **2009**, *87*, 22-29.
[9] M. G. Jones and A. R. Taylor, *Journal of Research in Science Teaching* **2009**, *46*, 460-475.
[10] T. Brosnan and Y. Reynolds, *Research in Science & Technological Education* **2001**, *19*, 69-78.
[11] D. L. Gabel, *Journal of Chemical Education* **1993**, *70*, 193.
[12] V. Y. Roadrangka, R. H.; Padilla, M. J. in *Group Assessment of Logical Thinking (GALT)*, *Vol.* Paper presented at the annual meeting of the National Association for Research in Science Teaching, Dallas, TX, **1983**.

Chapter 2:

Scaling and Anchoring/Unitizing Interviews of Students in Introductory Chemistry Courses

2.1 INTRODUCTION

Regardless if students enter the Science, Technology, Engineering, and Mathematics (STEM) fields as their career choices, many students are exposed to scientific decisions throughout their lives. From the progression of microchips to nanotubes, in order for technology to make leaps forward in our daily lives, it is essential that we take advantage of matter and its properties at the nanoscopic level. Due to this technological development as it pertains to scale, it is obvious why the focus of several recent studies have looked at how to students and experts interpret and move through the differently scaled worlds[1], [2], [3], [4], [5] and how they interpret the importance of scale when working in these worlds.

To determine where our students are in their understanding involves cognitive mapping of their knowledge. This is a very difficult task because every student's understanding varies dramatically as they all have had unique learning experiences. However, these learning experiences, and the understanding of concepts that students develop related to these learning experiences, tend to fall into patterns that allow researchers to consider a sample of students and their understanding of these concepts as a representation of the different ways students understand these concepts. Certainly, experienced teachers recognize these commonalities and incorporate this into their instruction (i.e. "students usually struggle to understand molecular shape and polarity so we now work with model kits"). Therefore interviewing a smaller, representative sample of students is the best way to create a general picture of their understanding. There have been entire books written on interviewing, but an example that is similar to what was used in this project was done by Bowen[6] which explored think-aloud methods.

2.2 LITERATURE REVIEW

In a major study done by Tretter, *et al.* [2], participants (grades 5, 7, 9, and 12) were given a Scale of Objects Questionnaire (SOQ) in which they were asked to identify size ranges of a variety of objects. They were then asked to sort the objects in order of their relative sizes. During this study, they showed that the perception of scaling changed based on an individual's experiences. They noted that all of the K-12 groups had difficulty ranking the 5 microscopic objects; however, the middle and high school groups had less difficulty than the elementary group. In addition, younger students reported that they found relative scaling easier to conceptualize than absolute scale.

Another study by Jones, *et al.* [3], an adapted version of the SOQ was used, known as the Scale Card Sort (SCS) to investigate the impact of exposing high-school aged participants to the film, *Powers of 10* (www.powersof10.com/film) and to then assess the students' comprehension of relative sizing. During the SCS interviews, students were given cards that had the name of an object or distance and a diagram or photo and asked to rank the objects from smallest to largest. The students were then asked to assign scientific notation labels to the cards. The students were then shown the film and re-interviewed. They found that all of the cards showed a statistically significant increase in placement accuracy pre-film to post-film (except for two: diameter of DNA had no change and the distance from Earth to the International Space Station had a small increase). When analyzing student scientific notation responses, they saw a mean increase of 20% in labeling the scientific notation to the card. In another study, by Jones and colleagues [5], novice (pre-service) and experienced teachers performed the same activities as well as an additional assessment called the Scale Anchoring Objects (SAO) that looked for participants' conceptual understanding at a variety of scales using objects to represent different size scales. As part of this, participants used their own bodies as a standard measurement. In the SAO, both groups performed perfectly when working at the human scale, however, both groups' accuracy decreased as they moved in both directions away from the human scale. This result was very similar to the results that were found by Tretter, Jones, & Minogue [4] where they also used the SAO with 5 groups of participants (Grades 5, 7, 9, 12 and doctoral students). In all studies it was noted that previous experiences in and out of school played an essential role in their scale abilities.

As a follow up to these studies, Jones and Taylor[7] summarized their findings as well as polling experts in a variety of fields. The experts were polled to determine if any commonality exists between the research findings on scale and the use and importance of scale skills by the real world experts. They also investigated what experiences contributed to the development of the experts' scale skills. The experts reported that scale was critical in their everyday work and many of them reported using their bodies as rulers (pacing off a building, estimating a tree height as number of human heights, etc). In addition to using their body as a ruler, the experts tended to have one or more "anchor points" which are spatial landmarks that were size references which they used frequently in their work. For example, a paleontologist noted, "I have two reference points. One is human size because humans relate very easily to human size. For dinosaurs, I use elephants (as a reference). So I would say this dinosaur weighed five elephants." (Pg 469) By working their ways to other sized worlds, experts either created units or used appropriate units based on the scale. This ability to use these new units for the specific application is called unitizing. A common example of unitizing is using a light-year as a unit for extremely large distances. It was reported that these anchoring and unitizing abilities were deeply rooted in previous experiences. The participants described a number of in and out of school experiences that contributed to their understanding of scale. Very few studies have been conducted on undergraduate students' conception of scale. A recent study of students in introductory engineering courses examined understanding of size and scale. Students were asked to create a scale for placing small, nonvisible objects (atom, virus) and visible objects (football field)[8]. The study found results similar to Jones and that students were at various stages in their development of number sense and proportional reasoning. Students in general tended to be accurate within the human realm and became more inaccurate as they moved away from the visible towards either end of the non-visible realms. The lower level students, when asked to create a line that all objects could fit on, created a scale that was linear which was very ineffective. Intermediate students attempted to create a log scale, however, created one incorrectly. The highest level students were successful in creating a correct log scale. The authors also agree that current instruction is not effective in helping students develop a sophisticated understanding of 'size and scale' and noting everything that the experts had reported as essential in their understanding, school experiences was a critical piece.

2.2.2 RESEARCH QUESTIONS:

- What is the scaling proficiency of students in general chemistry or preparatory chemistry?
- What is the anchoring proficiency beyond their visible world of students in general chemistry or preparatory chemistry?

2.3 METHODS

2.3.1 OVERVIEW

Interviews were performed at a large doctoral urban public institution in the Midwest. The interviews were broken into scale interviews and unitizing/anchoring interviews which were performed while sitting at a table. The entire interview was videotaped and photos were taken of all responses. The scale interviews (*N*=88 total) were conducted with students enrolled in preparatory chemistry (*N*=21) and the first semester of a two semester sequence of general chemistry (*N*=52). In addition, a group of experienced chemistry graduate students made up our expert group (*N*=15). The unitizing/anchoring interviews (*N*=44 total) were conducted with students enrolled in preparatory chemistry (*N*=13) and the first semester of a two semester sequence of general chemistry (*N*=16). In addition, a group of experienced chemistry graduate students made up our expert group (*N*=15).The research protocol is approved (IRB #09.047) and all included data is from students who consented via this protocol.

2.3.2 SCALE INTERVIEWS

The scale interview design was based on the interviews that were outlined by Tretter[2] and Jones[1] that was used in their work with K-12 students. Each interview was broken into four activities: 1) Bin Sort, 2) Ordering Within Bins, 3) Ordering With Measurements, and 4) Number Line. In activity 1 (Bin Sort), a smaller subset of the total (Phase 1: *N*=14, Phase 2: *N*=13) student interviews were examined for the bin descriptions used. Participants were asked to create bins that they could use to categorize object sizes and that would encompass the whole continuum of size. They were encouraged to leave the largest and smallest bins open on one end as a "catch-all" because they were not made aware of the spectrum to cover that also allowed us to keep their bins unbiased for specific objects. The participants were then given 20 objects (See table 2.1), which consisted of a subset of the items that Jones [3] used in their interviews. These sizes covered a large portion of

Interview Set 1	**Interview Set 2**
cell (7μm)	proton (2×10^{-14} m)
semi truck (20 m)	diameter of sun (1.4×10^{9} m)
atomic nucleus (10 fm)	water molecule (2.75×10^{-10} m)
bacterium (1 μm)	yeast cell (1.0×10^{-7} m)
textbook (28 cm)	sperm length (8.5×10^{-5} m)
virus (100 nm)	deer tick (3×10^{-3} m)
new pencil length (21 cm)	width of optic fiber (5×10^{-4} m)
Earth diameter (13 Mm)	silver nanotriangle (10^{-7} m)
finger (8 cm)	granulated sugar (300 μm)
Earth to Moon (384 Mm)	dime diameter (10^{-2} m)
Wisconsin state width (450 km)	postcard length (1.4×10^{-1} m)
cruising altitude of a 747 jet (11 km)	football length (28 cm)
football field (91 m)	doorway height (2.0×10^{0} m)
adult height (2 m)	telephone pole (6.1×10^{0} m)
hair width (100 μm)	10 story building (3.4×10^{1} m)
ant (2 mm)	width of Miller Park (3.3×10^{2} m)
Earth to Sun (146 Tm)	altitude of International Space Station orbit (3.5×10^{5} m)
New York to Los Angeles (4800 km)	Milwaukee to Orlando, Fl (1.7 Mm)
Postage Stamp (1.5 cm)	Earth circumference (4×10^{7} m)
atom (100 pm)	diameter of moon (1.7×10^{6} m)

Table 2.1 – Descriptions and sizes used during interviews.

the scale spectrum, both larger and smaller than human sized. They were then asked to sort the object by size into the bins that they created. The cards only had the description of the size such as “New York to Los Angeles” with no actual measurements given at this point. Because the sizes of many of the items lie well outside our normal everyday life objects, many participants commented on how overloaded their very large and very small end bins tended to get. In activity 2, (Ordering within bins), the participants ordered the objects in each bin by size with the smallest at the top. Participants were allowed to make changes between bins and again, actual measurements were not provided. In activity 3 (Ordering with measurements), actual measurements with units were provided with the description. They were asked to make any changes to the orders in their bins with the help of the new information. In activity 4 (Number line), the same items and information from the cards used in activity 3 (for example, New York to Los Angeles,4800 km) and a logarithmic number line was provided which extended from 10^{-9} to 10^{9} which also included a greater than and less than on both ends for those items which fell beyond those boundaries. If objects fell into the $>10^{9}$ or the $<10^{-9}$ categories, participants were asked to keep the objects in the correct ordering. The participants were asked to first define their unit for the number line and to place the objects as accurately as possible on the number line while maintaining a correct size ordering if more than one fell into a category. For the phase 1 interviews, the sizes were given with prefixed units (for example, 4800 km) and the number line was exponential. The phase 2 interviews used sizes in scientific notation in meters (for example, 4×10^{7} m) and the number line was changed to a decimal form with the same format as phase 1. The objects in phase 1 and phase 2 were different, but they were of similar magnitudes (for example hair width

(100 µm) and diameter of optical fiber ($5x10^{-4}$ m)) and covered approximately the same magnitude spectrum.

2.3.3 UNITIZING/ANCHORING INTERVIEWS

The unitizing interviews were performed using a similar time schedule to the scale interviews. These interviews were broken into 5 activities: 1) Sort to Scale, 2) How much Bigger?, 3) Comparison with Unitizing, 4) How Many?, and 5) Comparing Molecules. For activity 1 (Sort to Scale), the participants were given 20 images that were scaled to the same ruler under each image (see for example, Figure 2.1). The ruler itself had an increment size that was in centimeters however, it was labeled as true units to the object. An object that was actual size (an anchor object) was given so as to provide participants with a reference point (for example, a dime). They were then asked to create two piles comparing the image to the actual size. The two piles were "bigger", meaning that the image needed to increase in size to get to the actual size, and "smaller", meaning that the image needed to be reduced to get to actual size. For activity 2 (How much bigger?), the same cards were used and the students were asked to determine how many orders of magnitude the images would need to be increased or decreased by to get to actual size. They were placed on a magnitude spectrum accordingly so that the magnitude change would get it to the object's actual size. For activities 3 (Comparison with Unitizing), 4 (How Many?), & 5 (Comparing Molecules), the participants were asked to demonstrate their understanding of relative sizing by being asked to draw an object in comparison to a scaled object in a picture (See Figure 2.2).

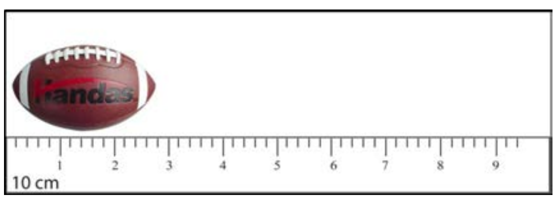


Figure 2.1 – Image of football scaled

For example, they were given a photo of a baseball stadium and asked to draw a baseball in comparison to the stadium, drawing a water molecule in comparison to a plant cell (shown in the figure), and drawing an atom or molecule in comparison to a larger molecule. They were then asked to determine how many of their drawn objects would fit across the pictured object. They repeated this process for a total of three comparisons, visible-visible, visible-non-visible, and non-visible-non-visible.

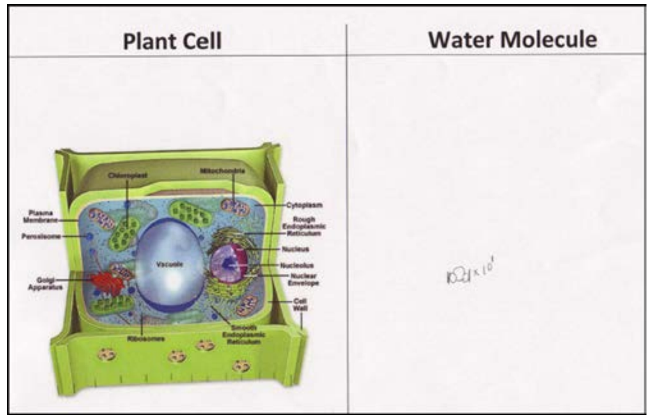


Figure 2.2 – Unitizing Interviews: Example for Activities 3, 4 & 5

2.4 RESULTS

2.4.1 SCALE INTERVIEWS

2.4.1.1 Activity 1: Bin Sort

The bin descriptions were tracked to examine how students categorize sizes. They were not given the twenty items so as not to cue them. When the descriptions were examined, 64% of the students chose other objects to compare the items to as their bin boundaries; for example, larger than a car but smaller than a building. All of the 14 students in their Phase 1 interviews had their smallest bin as something visible, commonly about 1 cm. When comparing their Phase 1 and Phase 2 interviews, only 7 of the 13 students that took both phases changed their smallest bin to something that is non-visible. Results of the binning of the objects are discussed in the following activities where the relative order (relative scaling) was investigated.

For Activities 2 and 3, student responses were compared with the correct rank order, meaning that their ordering the objects as compared to the other objects based only on the description (relative scaling). Their responses were then graded based on how many positions off the object was compared to its actual position (absolute scaling). The absolute scaling values were averaged for comparison of groups.

2.4.1.2 Activity 2: Ordering within bins

Examining the second activity results, students were asked to order the objects from smallest to largest relative to the other objects (aka, rank order). As shown in Table 2.2, all groups were able to place accurately more than 75% of the items, with the experts performing the best placing 90% of the items in the correct order. Examining each item placement more closely from the phase 1 items (Figure 2.3), it is evident that there are some areas where all groups have inaccuracies when ordering them with respect to the other objects. Even though there are mistakes with all of the items, the area of greatest concern is the item of hair width (which is approximately the limit of human sight) and smaller items. A value greater than 0 means that the item was placed in a position larger than it should be and less than 0.0 means that it was placed smaller. In addition, there are also some discrepancies with regards to some of the larger items, specifically the cruising altitude of a 747 and larger.

	Preparatory Chemistry Average		General Chemistry Average		Experts Average	
	Activity 2	Activity 3	Activity 2	Activity 3	Activity 2	Activity 3
Phase 1	80.9%	90.9%	78.7%	87.9%	90.0%	96.0%
	Z=2.113, p=0.035**		Z=3.611, p=0.000**		Z=1.841, p=0.066	
Phase 2	60.5%	82.0%	62.1%	78.3%	78.0%	89.0%
	Z=2.570, p=0.010**		Z=3.469, p=0.001**		Z=1.841, p=0.066	

Table 2.2 – Student performance in Activities 2 and 3 and the statistically significant increase (Wilcoxon Signed-ranks test, at 0.05 significance) in performance of providing measurements with the description.**

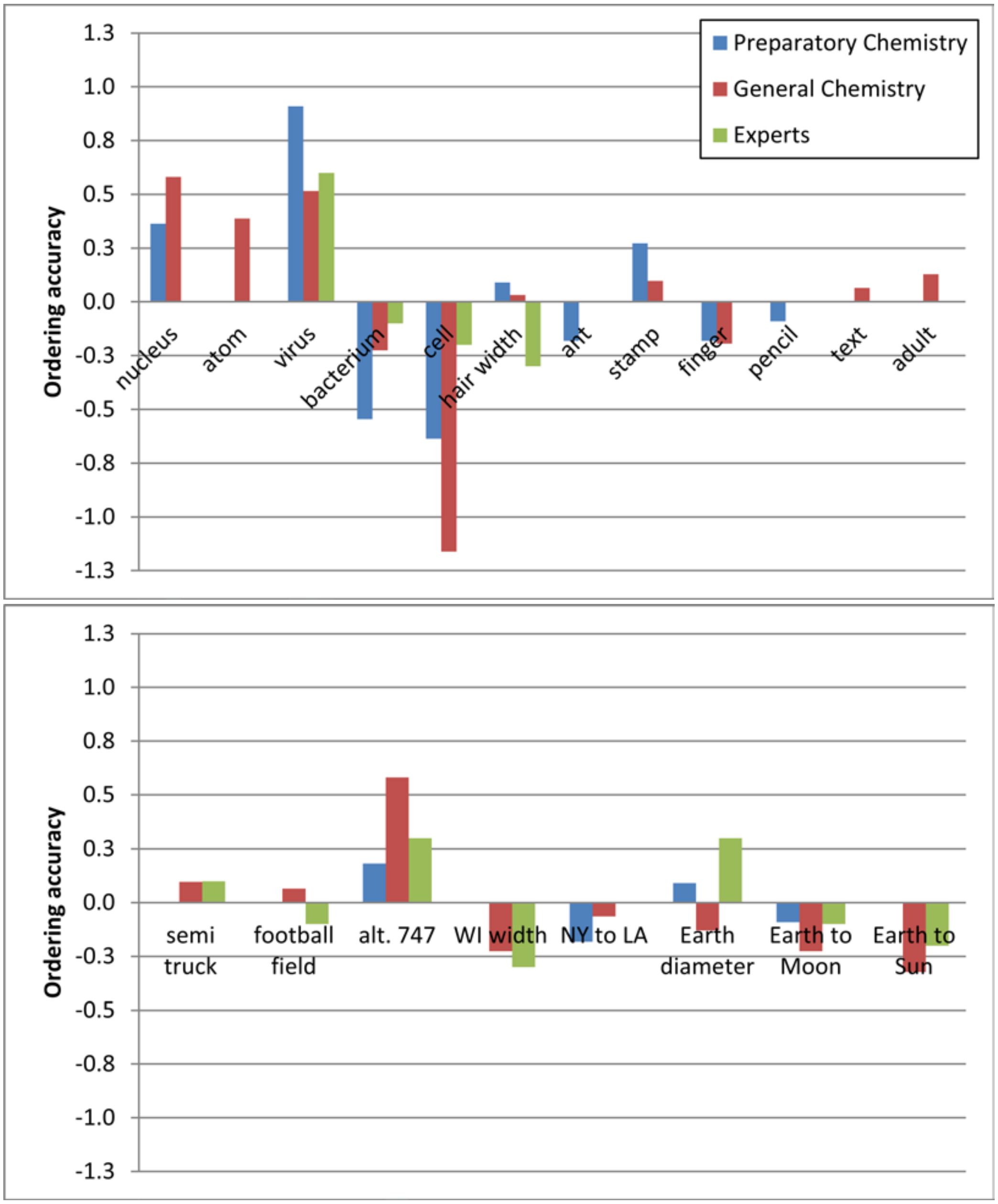


Figure 2.3 – Results of Activity 2, Phase 1 interviews. A value greater than 0 means that the item was placed in a position larger than it should be and less than 0.0 means that it was placed smaller.

2.4.1.3 Activity 3: Ordering with Measurements

In the third activity, students were provided with both measurements and the descriptions of the objects and given the opportunity to reorder if needed. A Wilcoxon Signed-ranks test was used to analyze the data because the data were not normally distributed. As shown in Table 2.2, the Wilcoxon Signed-ranks test shows a statistically significant increase in performance for both the preparatory and general chemistry students. Upon a closer examination of the individual items, it is obvious that the students, when given the actual measurements, made dramatic improvements with the majority of the objects, specifically the large objects. However, their performance was only slightly better with respect to the area that was of concern in activity 2; hair width and smaller items (Figure 2.4)

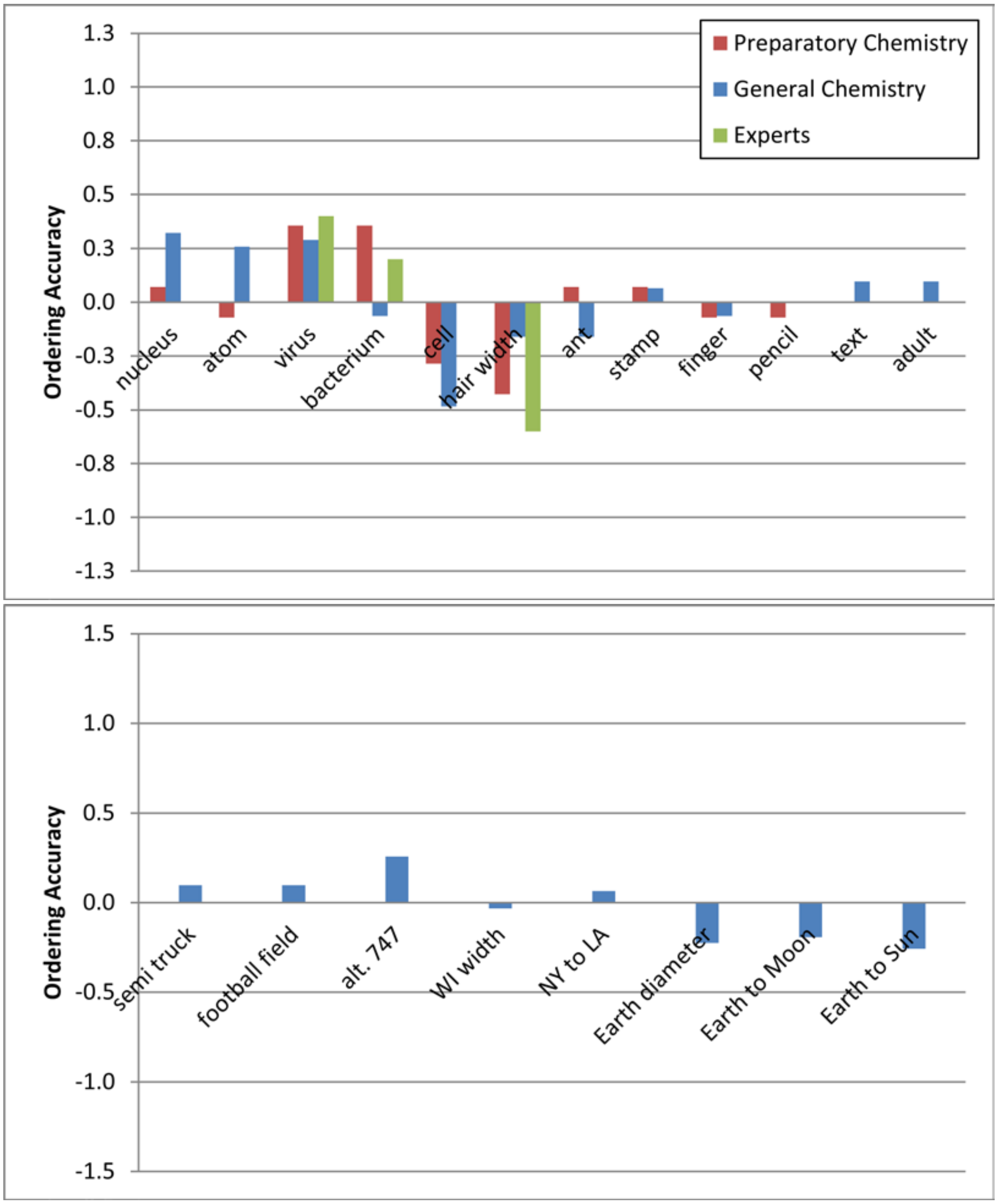


Figure 2.4 – Activity 3 (Ordering within Measurements) results of rank ordering. For the larger items, both the experts and preparatory chemistry students were perfect as a group.

2.4.1.4 Activity 4: Number line

Activity 4 provided students with both the description and the measurement of the objects and an exponential logarithmic number line in Phase 1 and a decimal logarithmic number line in Phase 2 on which to place them. Students were scored two ways. First, students were scored based on the location of the objects relative to the other objects (relative scaling). Again, the ordering was considered in both a positive (ordering the object larger than it should be) or negative (ordering the object smaller than it should be), similar to the scoring for Activities 2 and 3. The results of this ordering are shown in Figure 2.6. The students showed improvement in the hair width and smaller, however, a new region of concern has occurred for all groups. The area with regards to the finger, pencil, and textbook shows that students tended to place the finger about 1 magnitude larger and the pencil and text about 1-2 magnitudes smaller than actual. The second scoring method was now based on where it was placed on the number line and how many orders of magnitude the objects were placed as compared to the actual position (absolute scaling). Their answers were scored based solely on where they were on the number line and how many magnitudes their positioning were off as compared to the correct position. Increments of 0.5 magnitudes were assigned to each object and averaged. As shown in

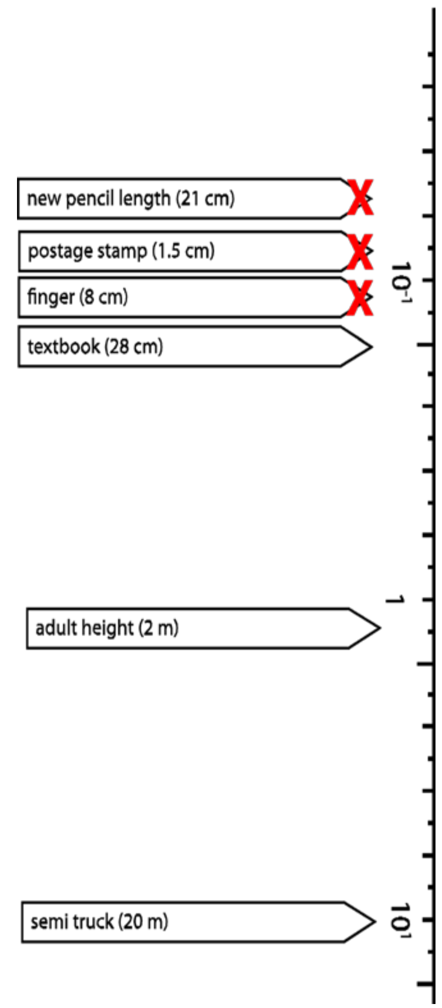


Figure 2.5 – Example of a student response on Activity 4 (Number line) and grading for absolute scaling.

Figure 2.5, the three marked with Xs are incorrect. For example, the new pencil length should be between 10^{-1} and 1, therefore it would be graded as a -1, meaning that it was placed one magnitude smaller than it should have been. This does not necessarily mean that they had them out of order relative to one another, but when placing them on the line, they were not in the correct place. For example, the text was placed up to 2 or more magnitudes smaller than it should have been and it was also out of place relative to the other items. But when we look at other items such as the virus, it was often in the correct place relative to the others, but off as compared to where it should have been. The results are provided in Figure 2.7. The results show that students struggle with both absolute and relative scaling of some of the nonvisible objects (virus, bacterium and cell). Additionally, students struggle with the absolute scaling of all objects in general as they deviate further from the 1 m or human size (unitizing to their bodies). The performance given for the very large and very small objects must be considered in the fact that these objects were placed into the "end" categories and only measured if they were placed into these categories and the correct ordering was maintained. The absolute scaling of the distance from the earth to the sun, for example, was not captured as this was placed into the "$>10^9$" category (unless a student selected a very large unit for their number line, which no one did).

Between phase 1 and phase 2, the number line was changed from exponent form to a decimal form based on comments by the students. They were asked if there was anything that could be changed to make it easier for them and nearly all of them said that it would have been easier with a line in decimal form. Ironically, even though the students had more difficulty with the phase 2 objects in activities 2 and 3 (see Table 2.3), their performance was better using the decimal line.

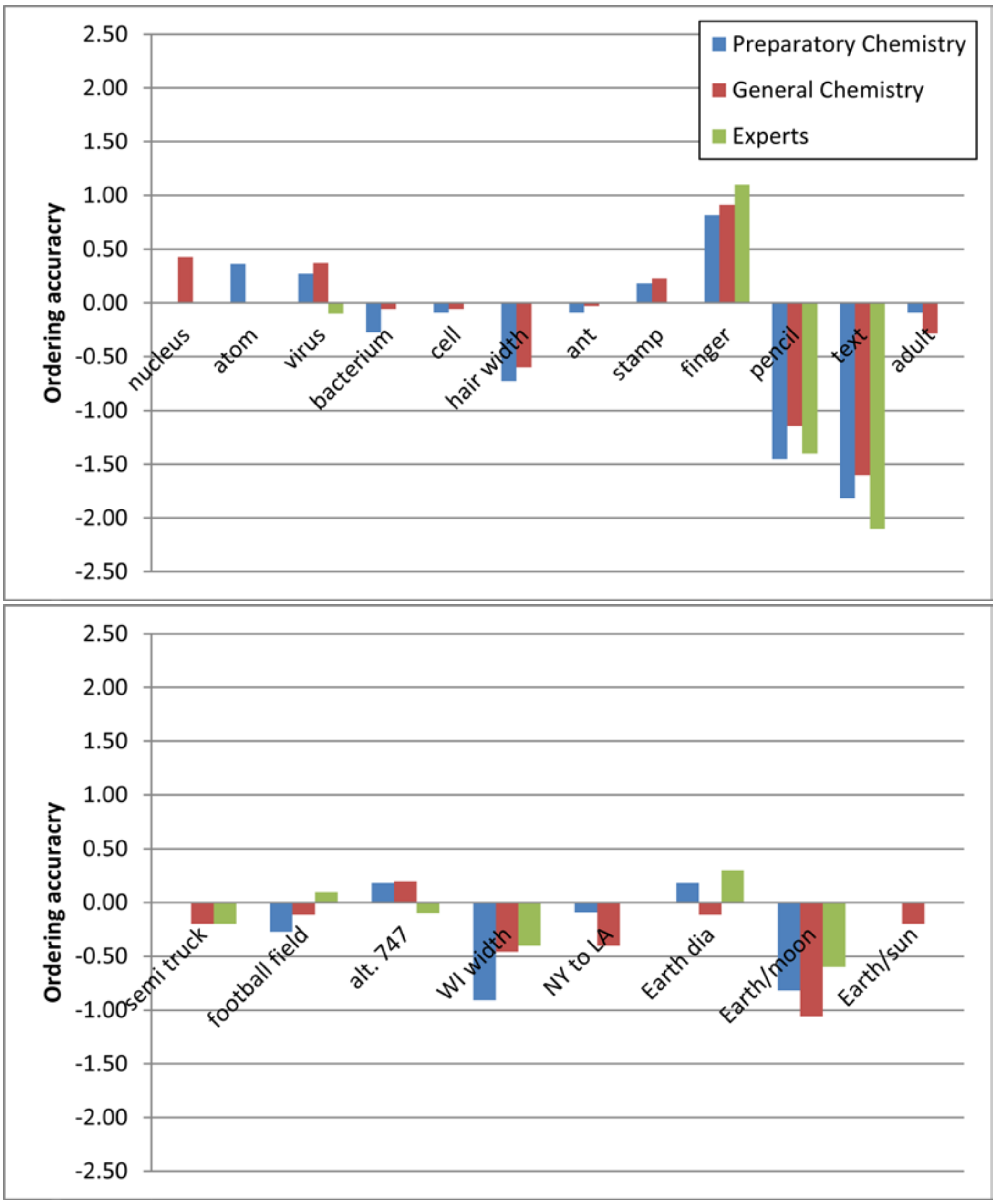


Figure 2.6 – Results of average relative item placement in phase 1, Activity 4 (Number line). Items that have a positive value were placed larger than actual and negative values mean that they were placed

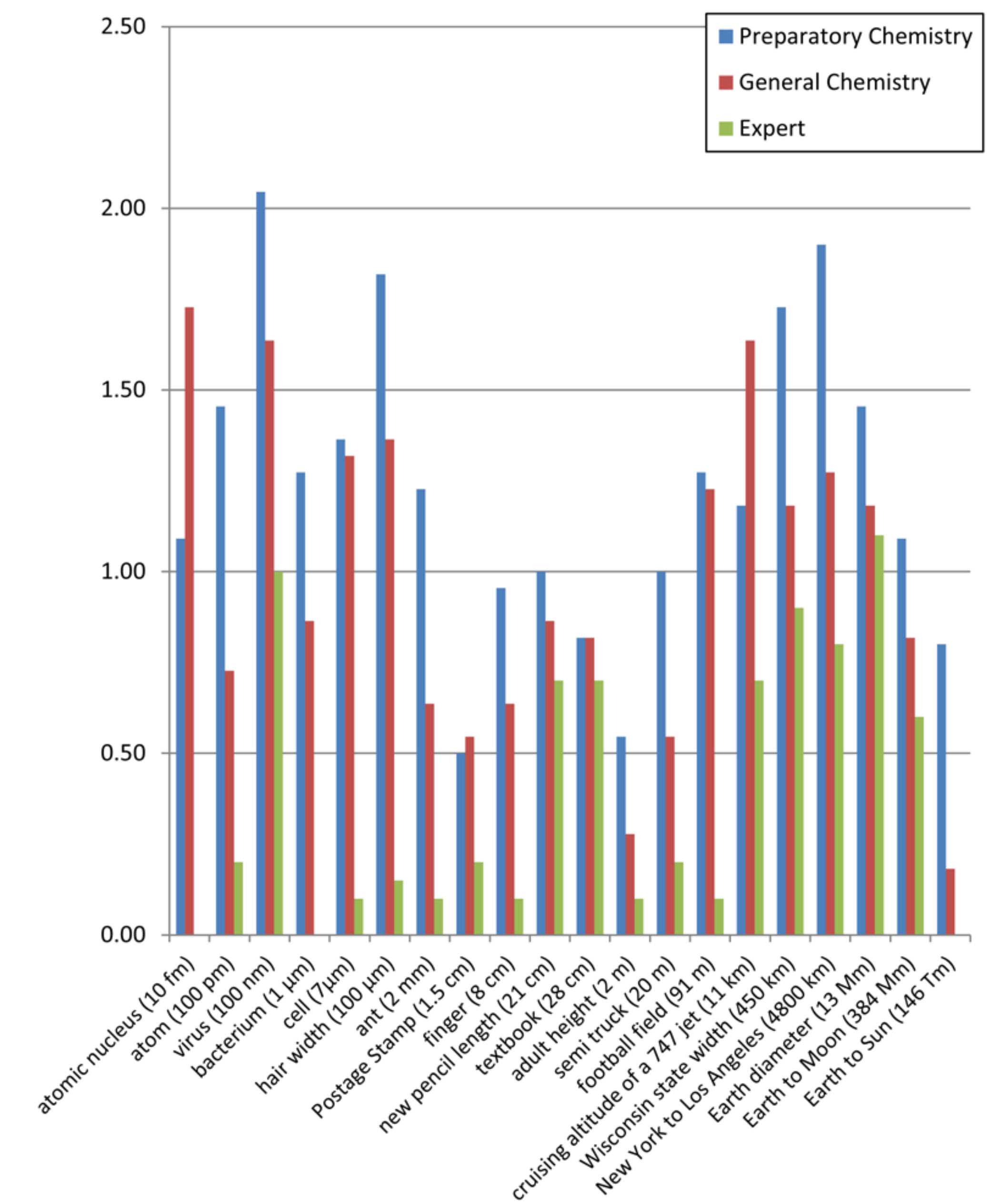


Figure 2.7 – Absolute scaling results of objects. The vertical axis is showing the average magnitude position. The closer to zero, the more accurate the placement.

2.4.2 RESULTS – UNITIZING/ANCHORING INTERVIEWS

2.4.2.1 Activity 1: Sort to Scale

In the initial activity, students were given the items and asked to sort them with respect to whether the image needs to get bigger or smaller to get to the actual size of the object. Students performed quite well on this activity with an accuracy of 89.5% which is approximately two objects out of twenty placed incorrectly. This tells us that students understand how images need to change to get to their real sizes.

2.4.2.2 Activity 2: How much Bigger?

Activity 2 examined how students move between scales. Students were asked to place item cards on a magnitude change continuum which was to represent how many orders of magnitudes the image would need to get bigger or smaller by to get to the items actual size. For example the football card that was shown in Figure 2.1, the student should have determined that the image is showing that the actual size of a football is 30 cm long and the scale that image shown to be in 3 cm. There is a 1 magnitude difference between the image and the actual and therefore their answer should have been +1 on the magnitude continuum. The total number of orders of incorrect magnitudes was averaged for all students and is shown in Figure 2.8. The expert group was better at determining the magnification needed to get the image to the objects actual size. When we look closer at the individual items (Figure 2.9), it is apparent that the performance decreases substantially as we move further away from the human scale towards the extremes.

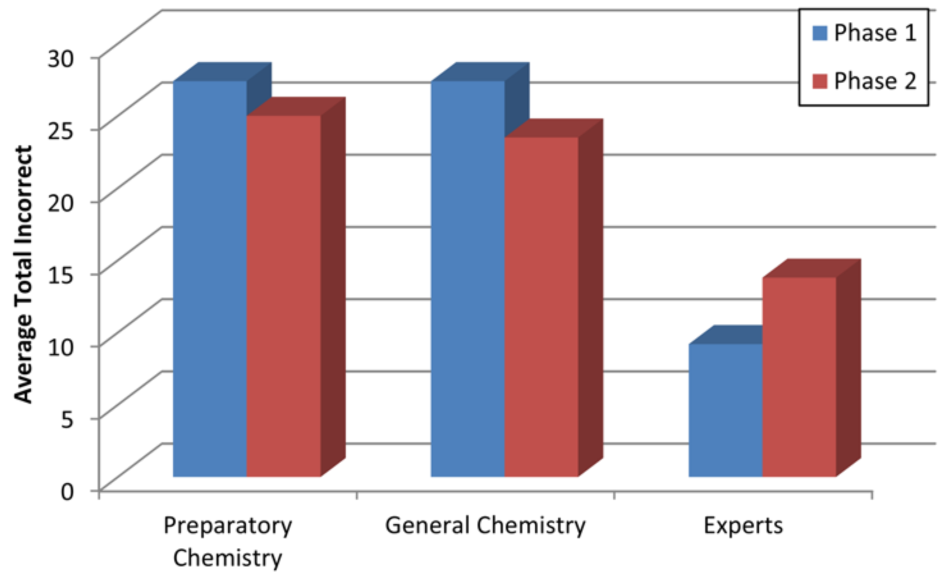


Figure 2.8 – Average amount of total magnitudes off for total items by group. Total positions off summed and averaged over all participants.

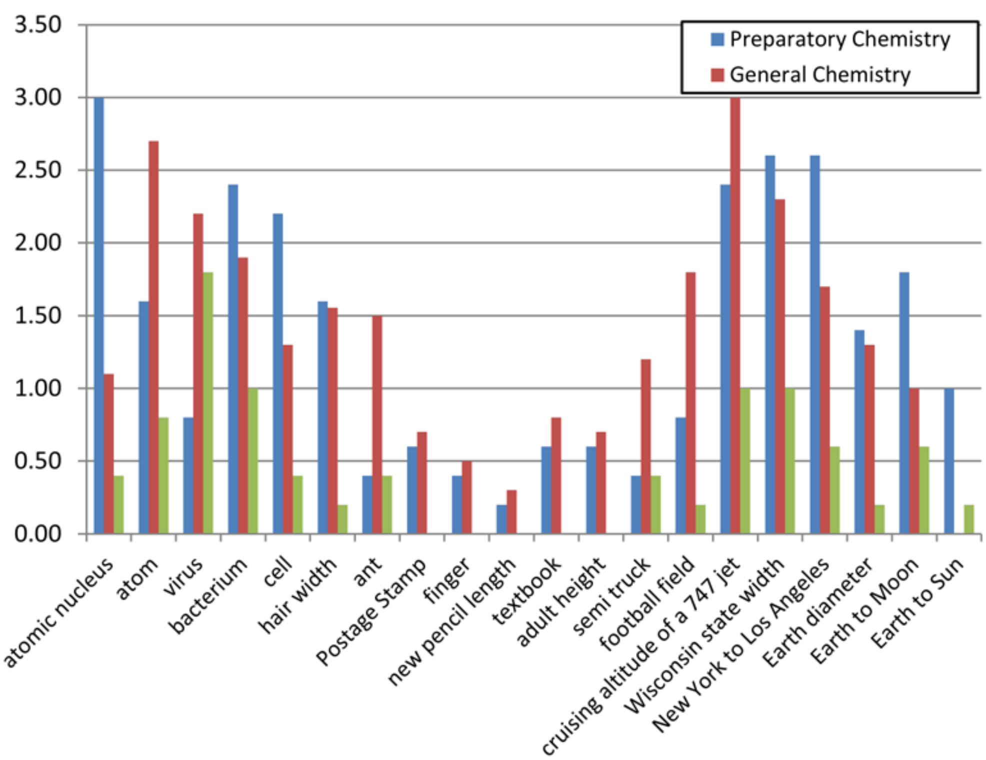


Figure 2.9 – Activity 2 (How much Bigger?) results of average magnitude errors for each item. The vertical axis shows the average magnification answered. The closer to zero, the more accurately it was placed.

2.4.2.3 Activity 3: Comparison with Unitizing

In phase 1, students were given a picture of a local baseball stadium and asked to draw a baseball in comparison to the picture of the stadium and a picture of a plant cell and asked to draw a water molecule in comparison. In phase 2, students were asked to draw a cell as compared to a hair width and select and draw their choice of object as compared to a picture of Earth. As shown in Table 2.3, the expert group did perform better with the drawings from both phases. Although the visible-visible comparison of the baseball to stadium showed the best performance in the Phase 1 interviews for the experts, the novices were able to perform the best with the visible-non-visible comparison of the cell to hair width. In Figure 2.10, three examples are shown of the variety of students' responses in drawing their responses.

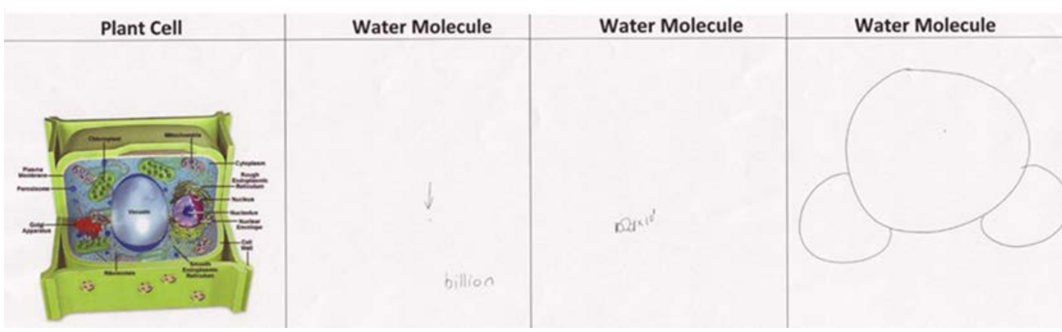


Figure 2.10 – Example of the image of a plant cell that was given to the students and actual drawings by three of the participants.

In phase 2, a picture of Earth was given to the students and they were allowed to choose their own object to draw in comparison to Earth. 38% of the students chose the Moon as a comparison. 50% of the students used something that was able visible on the image such as states or continents (no borders for states or countries were given). Nearly 12% of the students used another object that would not have been visible in the image such as a bus, a boat and even a basketball.

	Novice			Experts		
	accurate	too large	too small	accurate	too large	too small
Baseball to Stadium*	33%	66%	N/A	80%	20%	N/A
Water Molecule to Plant Cell*	12%	88%	N/A	60%	40%	N/A
Cell to hair width*	40%	20%	40%	30%	10%	60%

Table 2.3 – Results of comparative drawing for novice (preparatory and general chemistry students) and expert groups. (*) shows the image given. (Phase 1 – Baseball to Stadium and Water Molecule to Plant Cell; Phase 2 – Cell to Hair Width)

2.4.2.4 Activity 4: How Many?

After the students had drawn their comparison objects, they were then asked to determine how many of the drawn objects would it take to go across the given object. Student responses were varied but often they were relative to their drawing. As we can see in figure 2.9, the student with the largest water molecule provided an answer of 1 whereas the one with the smallest, and most accurate picture, answered a billion. Connecting their conceptual idea of size with an actual value was a difficult task for them.

2.4.2.5 Activity 5: Comparing Molecules

Activity 5 is similar to Activities 3 and 4 except it was strictly comparing molecules to other molecules and atoms. In addition to the drawing, the participants were also asked to determine how many would be needed to be the same diameter or length of the molecule given. In phase 1, students were given a buckyball (ball-and-stick) and asked to draw both a carbon atom and a water molecule in comparison. In phase 2, the students were given a space-filling model of a large long molecule ($C_{20}H_{42}$) and asked to draw a water molecule in comparison to it. As can be seen in Table 2.4, the expert group performed relatively better, however, it appears that their understanding of the relative size of a carbon atom to an oxygen atom appears to be skewed based on the results of comparing the water molecule to the long $C_{20}H_{42}$ molecule. The novice group performed admirably on the carbon atom to buckyball because most of them recognized that the buckyball was made of carbon atoms and therefore used that as their reference However, they struggled when asked to compare the water molecule to the carbon atoms in the buckyball. Even though they recognized that there were carbon atoms in the pictured molecule and that there was oxygen in a water molecule, they seemed unable to appropriately size the atoms. This was similarly a problem when comparing a water molecule to the long $C_{20}H_{42}$ molecule.

	Novice			Experts		
	accurate	too large	too small	accurate	too large	too small
Carbon Atom to buckyball *	73%	7%	20%	80%	10%	10%
Water Molecule to buckyball*	20%	20%	60%	70%	20%	10%
Water molecule to $C_{20}H_{42}$*	33%	7%	60%	40%	20%	40%

Table 2.4 – Results of comparative drawing for novice (preparatory and general chemistry students) and expert groups. (*) shows the image given. (Phase 1 – Buckyball comparisons; Phase 2 – $C_{20}H_{42}$ molecule)

2.5 DISCUSSION

The results show that students struggle in many areas of scale and unitizing and of moving among various units. From the scale interviews, it appears that the students have real misconceptions regarding the size of objects and this effect is magnified as we move in both directions away from the human realm. It appears that their weaknesses in number sense, estimation skills, converting between scales, and sizing relative to other objects seems to magnify their misconceptions and hinders them in being able to move efficiently across many magnitudes of sizes. For example, when we look at the issues with the visible objects (pencil, finger, and textbook), this performance may reflect on their difficulties with number sense. These ideas were confirmed during the unitizing/anchoring interviews. During the comparative drawing, it was obvious that when working with two non-visible items, specifically the cell and water molecule, student have a very skewed perception of relative sizes and this obvious shortfall may hinder them from completely understanding many concepts in biology and chemistry. These interviews also made it quite clear that the students were continuing to struggle with moving between scales and that this skill was made more difficult when the students did not know how to re-anchor themselves along the way. The students that reported anchoring (although they didn't necessarily use the term) stated that the maximum re-anchor points were about 3 orders of magnitude from their anchor. Their performance decreased substantially when they were asked to compare objects of more than 3 orders of magnitude difference in size. This three orders of magnitude (or 1000 times) was confirmed after the fact in the *Project 2061: Benchmarks for Science Literacy*[9]. For example, we can think of what a millimeter looks like and we can envision 10 of them making a centimeter and envision 1000 millimeters in a row; just look at a meter stick. It would also be pretty easy to envision a meter and even 10 meters, and a quick jog would be 1000 meters, however, it becomes nearly impossible to think of a kilometer as a million millimeters or 6 orders of magnitude. To add to the difficulty, students are required to use exponent form, which presents an additional challenge because their number sense is another area of weakness. The comparison drawings presented another challenge that didn't need the students to utilize numbers but rather their perception of scale. When drawing a non-visible relative to another non-visible, it was apparent that if they had a reference in the image, they could be relatively successful such as a carbon atom to a buckyball. However, when presented with another molecule, such as water, they majority drew them too small therefore their perception of the relative sizes of two quite similarly sized atoms (carbon and oxygen) is skewed.

2.6 CONCLUSION

Students in introductory chemistry have a deficiency in both relative and absolute scaling, particularly as these sizes get farther from human size. In addition the students have such a varying range of proficiency that addressing the variance is difficult. When students were required to move three orders of magnitude or more beyond their own bodies, their performance dropped dramatically in both relative and absolute scaling. Additionally they showed little evidence of anchoring on the molecular level as seen in the comparison drawings. This suggests that students have not developed or used the skills to scale beyond the visible realm. The skill of anchoring is critical in helping students move efficiently through the spectrum of sizes particularly small sizes critically important in science. Since students come from different educational backgrounds, it is apparent that this skill set is not being taught adequately at earlier levels regardless of their backgrounds, yet we as instructors often assume that the students have developed and can use these skills. Within the more experienced group, their performance was relatively better, and it was clear that extended time in the field of chemistry, aids development in the areas of scale and unitizing.

With our technological world moving further from the human scale, such as astronomers looking at quasars at the edge of our universe and using nanocircuits in computer chips, it is essential that students begin to understand the world around them beyond their visible world. So, where does this leave us as educators? Although we can learn much from the interview process, it would be very difficult to make these same measures in a large classroom environment. With the new national science standards, curriculum changes are on their way. This however, may be a bigger hurdle than expected. It will be critical to develop not just a classroom unit on scale but develop a holistic approach where scale is a continuous theme throughout the curriculum. Additionally, in order to design instruction centered on incorporating the theme of scale into this instruction, assessment instruments must be developed and tested to measure the efficacy of this instruction. These assessment instruments must easily capture the scaling skills of students as well as the concepts and misconceptions that students have with regard to scale.

2.7 REFERENCES

[1] T. R. Tretter and M. G. Jones, *Science Teacher* **2003**, *70*, 22-25.
[2] T. R. Tretter, M. G. Jones, T. Andre, A. Negishi and J. Minogue, *Journal of Research in Science Teaching* **2006**, *43*, 282-319.
[3] M. G. Jones, A. Taylor, J. Minogue, B. Broadwell, E. Wiebe and G. Carter, *Journal of Science Education and Technology* **2007**, *16*, 191-202.
[4] T. R. Tretter, M. G. Jones and J. Minogue, *Journal of Research in Science Teaching* **2006**, *43*, 1061-1085.
[5] M. G. Jones, T. Tretter, A. Taylor and T. Oppewal, *International Journal of Science Education* **2008**, *30*, 407-427.
[6] C. W. Bowen, *Journal of Chemical Education* **1994**, *71*, 184.
[7] M. G. Jones and A. R. Taylor, *Journal of Research in Science Teaching* **2009**, *46*, 460-475.
[8] S. Swarat, G. Light, E. J. Park and D. Drane, *Journal of Research in Science Teaching* **2011**, *48*, 512-533.
[9] *Benchmarks for Science Literacy*, Oxford University Press, **1994**, p.

Chapter 3:

In-Class Activities Targeting Scaling and Unitizing Concepts in Introductory Chemistry Courses

3.1 INTRODUCTION

An old Chinese proverb says, “Tell me and I’ll forget, show me and I may remember, involve me and I’ll understand.” This has been supported by theories in cognitive psychology especially with memory and learning. Didactic lecture is normally the method used in large lecture halls, however, it can be debated that this passive form of learning is not the most effective method for teaching students.

George Bodner, a constructivist from Purdue University stated, “Teaching and learning are not synonymous; we can teach, and teach well, without having the students learn.”[1] In his quote, Bodner is referring to the difficulty of not just getting the information to students, but having them actually learn the information and in a meaningful way. Delving deeper into the learning theory of constructivism, one could connect to Piaget and his model of intellectual development.[2] Piaget argued that we construct our own knowledge as a learner and that each of us sitting in a lecture hall, even though we are having roughly the same experience, will construct our own knowledge differently. So, how can we expect all of our students to be at the same spot of understanding at the end of the day? Piaget’s theory about how we store information cognitively involves structures or schemas. Because we all have different prior experiences, our initial schemes differ. Therefore each student will file the new information differently as well as make some connections with prior knowledge, even though these connections may be right or wrong. This begs the question of how do we move students from their current knowledge to accommodate new knowledge as well as make all of the connections that need to be made for understanding?

Creating an effective intervention that can be performed in a timely manner as well integrating it into the typical curriculum can be a challenge. It is also important to have a method to determine the impact of the intervention.

3.2 LITERATURE REVIEW

Understanding where novices and experts differ in their understanding of scale can be a valuable starting point to begin developing the path to understanding. In a study done by Jones and Taylor [3], they focused on this difference by looking at how experts in their fields came to understand scale in the world around them. They chose their expert participants based on their type of profession; however, it was important that the profession, scale would be used on a regular basis. The researchers found that although the variety of professions utilized a wide variety of tools for measurement and scaling, there were some commonalities among them which included using their bodies as rulers and using anchor points as size references. The participants also noted that there were in and out of school experiences that exposed them to the ideas of scale early on and that were impactful experiences. These included scaling models and maps, creating maps, and hands on activities such as measuring using instruments. The researchers also noted when looking at the experiences from child to adulthood, the knowledge of scale was not based on a one time occurrence, but rather repeated use and a strong development of visual spatial skills. Participants described visual processes that are carried out mentally when they are working with differing scaled worlds. This was noted in a variety of fields including engineering, biology, construction, and neurology, just to name a few. Jones and Taylor go on to summarize, “Across professions the participants emphasized the critical role that scale plays in their work. Scale was not just important, but in many cases was viewed as a central to accomplishing the work-related tasks.”(Pg 472) In another study[4], participants of various levels of scale experiences were interviewed and experts that had instrumentation experience relating to the very small performed better on their sense of scale. They noted that it was experiential exposure to scale that fed into developing their conceptualizations of scale.

Moving the students forward to understanding scale and the particulate nature of matter appears to be deeply rooted in their experiences; however, as was stated earlier, there is another area where we, as educators, need to take into consideration Piaget’s Learning Theory. A study done with 9th grade students by Tsitsipis, Stamovlasis, and Papageorgiou [5] examined how the three cognitive variables of dependence/independence, convergence/divergence, and logical thinking were related to the students’ understanding of the particulate nature of matter and its changes of state. The researchers found that there was a statistically significant correlation between the cognitive variables and the students understanding of the particulate nature of matter and state changes. When considering this information, they concluded that biggest impact on teaching this is the concern that students have an insufficient access to formulate reason, which was found to be the largest source of their difficulties. This means that teachers are required to use techniques that make abstract ideas more accessible through concrete thoughts and exercises.

Several studies have looked at different approaches to teaching interventions. Jones, Taylor, Minogue, Boradwell, Wiebe, and Carter investigated how the film “Powers of Ten” could impact the students’ understanding of scale. Even though the film is a small intervention, they found that it had a significantly positive effect on students’ understanding. Other studies have taken this idea of exposing students to another level by providing hands-on experiences to students at the atomic level. This has been done by growing all of the atomic scale to a human scale such as done by Tretter[6] with high school aged students by providing an experience using instrumentation including atomic force microscopes[7], scanning probe microscopes[8], and scanning tunneling microscopes[9]. In all situations, students were exposed to the atomic world that helps them develop the tools needed to make conceptual transitions from the human scale to the atomic scale.

3.3 METHODS

3.3.1 OVERVIEW

The experiment was performed at a large doctoral urban public institution in the Midwest. Phase 1 of the modules was conducted during lecture periods with students enrolled in preparatory chemistry (N=109) and the first semester of a two semester sequence of general chemistry (N=148) in the fall semester of 2008. Phase 2 was implemented the spring of 2009 where a treatment/control experiment was done performed with the preparatory chemistry students (treatment N = 155; control N=150) and first semester general chemistry class (*N*=129 total). Phase 3 was started during the fall semester of 2010 with ongoing use since then in all semesters of general chemistry I and preparatory chemistry (average *N* = 280 per semester). The research protocol is approved (IRB #09.047) and all data included is from students who consented via this protocol. Student demographic data can be found in the supplemental materials.

3.3.2 MODULE DEVELOPMENT

The design of the modules followed the two studies by Jones and her colleagues which used the *Powers of 10* movie[10] and the remote use of an atomic force microscope[7] to expose the students to differently scaled worlds. Participant interviews provided additional information about where our students were with their understanding and therefore the modules were designed to fit their needs.

The modules were developed to their current state in three phases. In phase 1, there were two modules (1. Scale and 2. Unitizing) which included viewing movies of images of the same objects at different magnifications fluidly joined together and multiple objects of different sizes threaded together (similar to the *Powers of Ten* movie). These modules didn't involve the students in any way with the instrumentation. The activities involved a live scanning tunneling microscope (STM) and a remotely operated scanning electron microscope (SEM). The scale activity was broken into three parts: Fiber activity - magnification by factors of two; Identify the object activity - magnification of a tick by factors of two and ten; Powers of ten - magnification of silver nanotriangles by orders of magnitudes. The unitizing module was also broken into three parts: Graphite discussion - particle vs macroscopic of both lubrication and conductivity;

Powers of ten images – ten orders of magnitude presented from a tree to an atom; Particle vs macroscopic follow-up discussion.

It was determined that the modules needed to be redesigned because it was apparent that the modules were not effective in helping the students in their scale proficiency. Even though Jones[10] found that students performed better after watching the *Powers of 10* movie, we found that our students weren't engaged and were passive in their learning. We determined that it was important to incorporate inquiry into the modules. To help make them accountable for keeping up with the rest of the class and the material, the students were required to choose what to look for, the instrument to be used and the magnification that they needed. The use of the student response "clicker" system was used to live tally the class. In phase 2, there were still two parts, however, many of the movies from phase 1 were eliminated and some inquiry was incorporated into the activities that allowed the students to interact more with the instrumentation. In addition, it was determined that during phase 1 that the material was too advanced and was made more accessible using a scaffolding approach with the material. The phase 2 modules incorporated two additional light microscopes in the classroom. The scale module consisted of two main activities that included a "CSI"-type identification activity that focused on magnification activities and used images to determine the magnifications. The unitizing module focused on lubrication of graphite which used macroscopic and particle images collected real-time and worked to engage students to work with particle and macroscopic representations which incorporated relative sizes of atoms and molecules.

In phase 3, the two separate activities from phase 2 were merged and shortened. Because the inquiry portion of the activities appeared to be critical, the focus of the activities shifted to maintaining that aspect of the modules. Copies of all activities can be found in the supplemental materials.

Assessment of the effectiveness of the modules was done using a student response system. The students answered a series of 5 questions two lectures prior to when the module was concluded. Another set of 5 questions, clones of the first, were asked the day before the module and after the instruction on the content for the module was complete. These were coined the pre-module questions. Another series of 10 post module questions (clones of the first sets) were asked over the two lecture periods after the presentation of the module. These questions were used to determine if any performance change occurred in addition to retention of the material.

3.4 RESULTS

The phase 1 modules were given during the fall 2008. To determine the effectiveness of the modules, the performance on the two sets of pre-questions is compared to the two sets of the post-questions. Looking at the trend of the scale questions from before the module to after the module (Figure 3.1) shows minimal improvement which is not a statistically significant gain. The results of the unitizing questions again did not show a statistically significant gain in performance for either group.

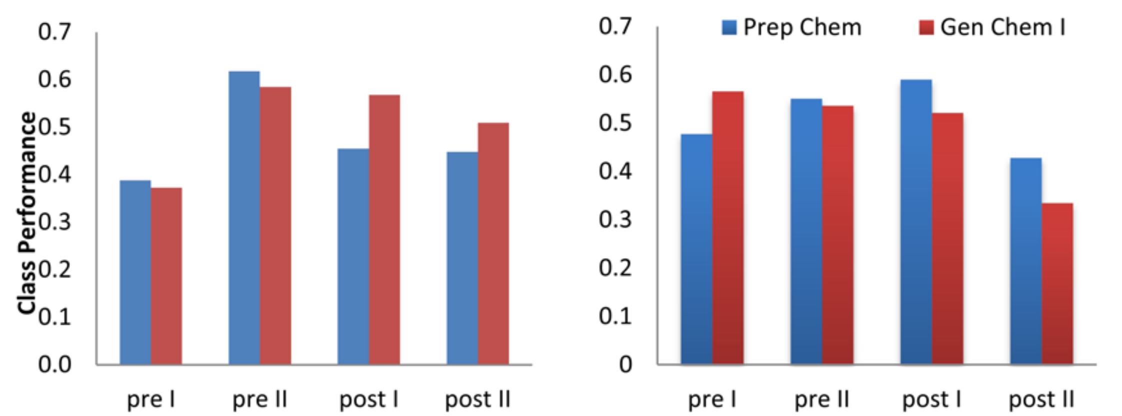


Figure 3.1 – Results of phase 1 scale(left) and macro/particle(right) assessment questions during Fall 2008. The class performance is the average correct based on a scale of 1 which would mean everyone answered correctly.

The phase 2 modules were implemented starting during the Spring 2009 semester with the same groups. These modules used the same content from the first phase; however, it was presented in a way that allowed for the students to make the decisions. The pre- and post-assessment questions were also modified to better reflect what was expected to learn. As you can see from Figure 3.2, the performance improved on both the scale and macro/particle questions.

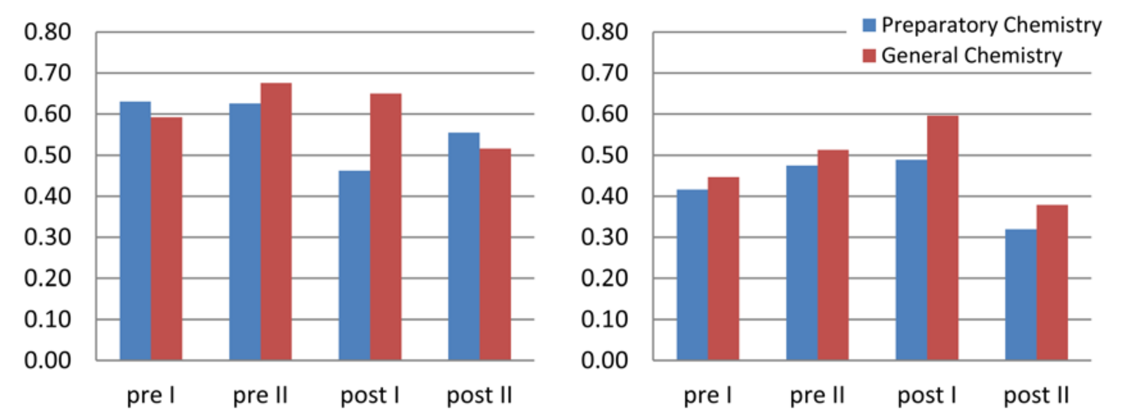


Figure 3.2 – Results of phase 2 scale(left) and macro/particle(right) assessment questions during Spring 2009. The class performance is the average correct based on a scale of 1 which would mean everyone answered correctly.

Since scale encompasses both conceptual and algorithmic areas in chemistry, it was important to compare the scale results to the chemistry placement exams which assess both the students' math and science abilities. Figure 3.3 shows the correlation

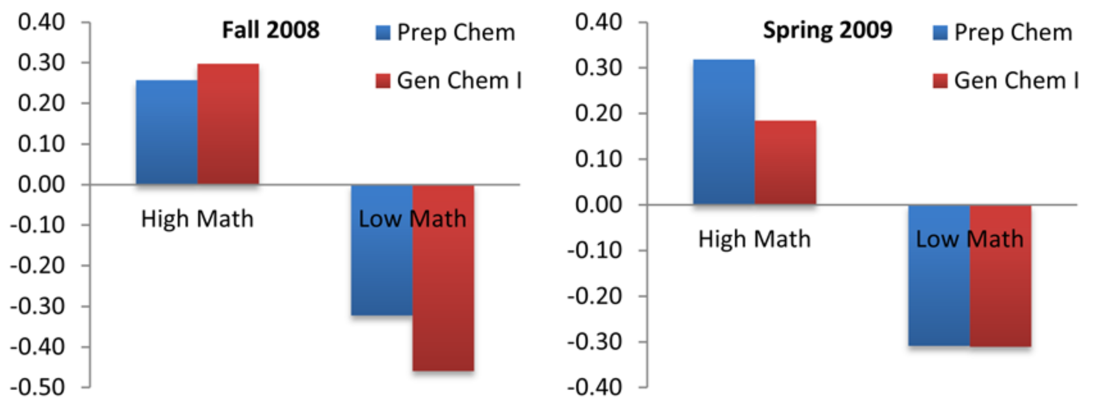


Figure 3.3 – Examination of scale performance vs. math placement exam performance. The vertical axis represents the average score based top score of 1.

between the placement scores and scale performance. It is quite apparent that in the Fall 2008 and Spring 2009 data, a high scale ability is directly related to a high math ability. Understanding scaling does require a substantial understanding of numbers and number sense, however, it is important that we continually make the connection to the chemistry content. When comparing the Fall 2008 scale performance to both the chemistry and math placement scores in Figure 3.4, it is apparent that to be successful on the phase 1 assessment, the student's math skills were more important than their chemistry skills.

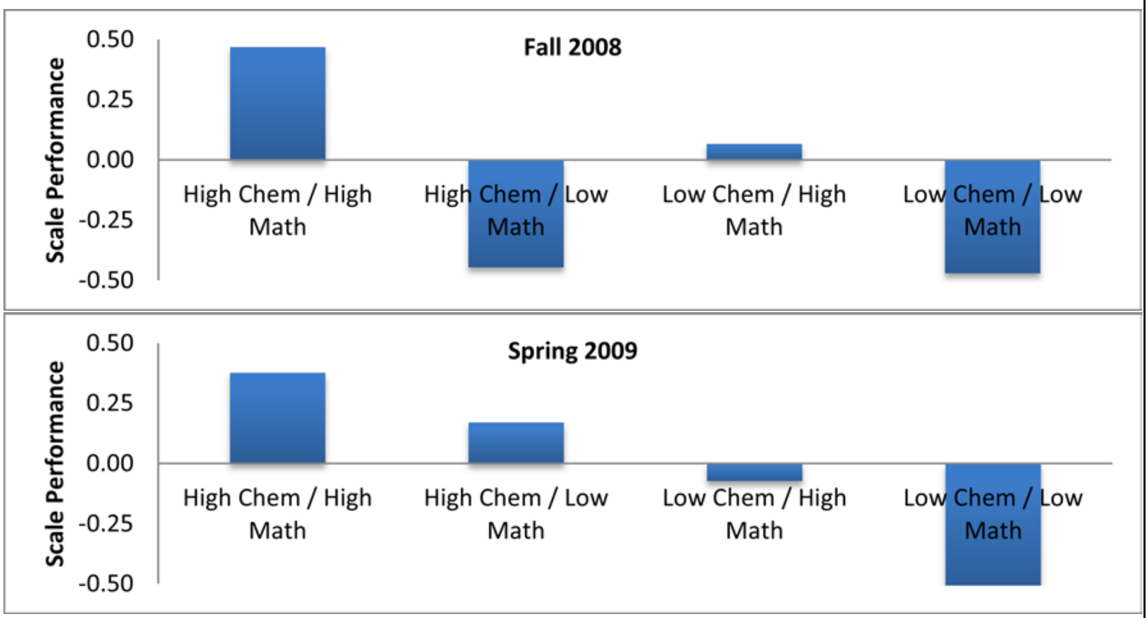


Figure 3.4 – Examination of scale performance vs. both math and chemistry placement exam performance. The scale performance is based on the average score for a group with a maximum of 1.

This was a concern and therefore during the redesign of the modules, an effort was made to create a better connection to the chemistry content and therefore as can be seen in the Spring 2009 data in Figure 3.4 as that students with higher chemistry placement scores performed better with regards to the scale performance rather than the high math scores being positively correlated. It is apparent that the changes in the phase 2 modules were effective in assessing scale with respect to both math and chemistry knowledge.

The macro/particle assessment was examined to see if students did better on algorithmic or conceptual questions. As can be seen in Figure 3.5, there is a statistically significant increase in performance for both groups on the conceptual questions of the assessment. Interestingly, there was a statistically significant difference between the groups with the pre and post questions and the preparatory students surpassed the general chemistry students; therefore there was no longer a difference between them. For the algorithmic items, neither group performed exceptionally well. Additionally, the questions did get progressively more difficult and therefore it was expected that the performance may wane slightly as a result.

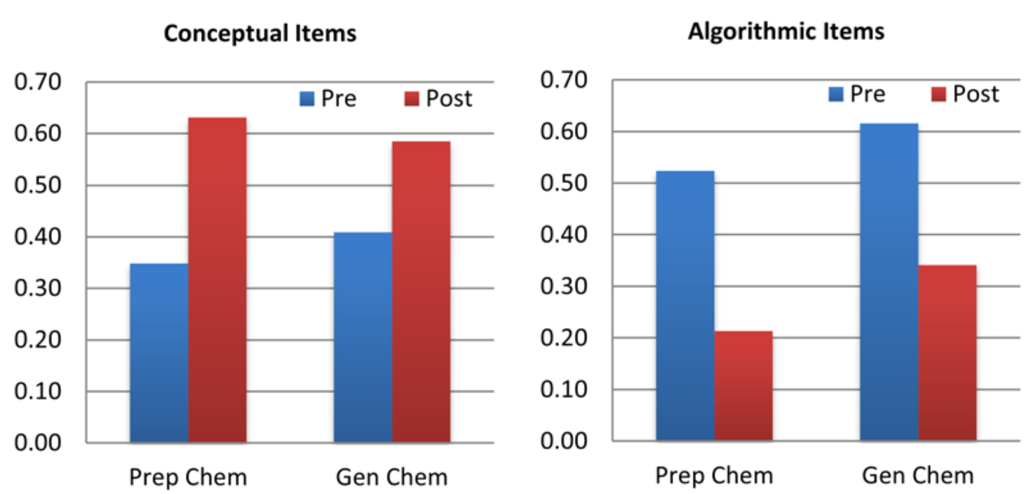


Figure 3.5 – Macro/Particle (Spring 2009) assessment questions categories of conceptual and algorithmic.

3.5 DISCUSSION

Creating appropriate modules that benefit students was not a simple objective. It was critical to set appropriate goals for the students based on the students' current performance level. As evident by the chemistry and math placement scores, scale isn't just about the mathematics, it relies on an understanding of chemistry as well. It was evident that just because a student can convert and understand numbers, doesn't mean that they will be literate in scale. Using the student response system was an effective, but not perfect way, to retrieve their answers since they could change their initial answers and they could potentially share answers. It was determined that showing them a movie and expecting them to absorb the information was highly impractical and showed not to be effective at all. Adding inquiry and allowing the students to make decisions on their learning turned out to be critical to keeping them engaged and therefore retaining the material.

3.6 CONCLUSION

Providing learning experiences for students in class is essential; however, measuring the effectiveness is another issue. Creating an exciting lesson, doesn't necessarily mean it is an effective lesson. Retention of the content beyond the initial intervention is important to consider and even though this preliminary study shows that utilizing instrumentation and inquiry is important for an initial learning, scale needs to be considered as an inclusion curriculum wide rather than a 1 or 2 day event. Understanding earlier where the students are at in their understanding enables the instructor to choose more appropriate lessons and therefore be able to focus on the skills to be developed therefore in order for these modules to be more effective, one needs to be able to better measure their current understanding.

3.7 REFERENCES

[1] G. M. Bodner, *Journal of Chemical Education* **1986**, *63*, 873.
[2] D. M. Bunce, *Journal of Chemical Education* **2001**, *78*, 1107.
[3] M. G. Jones and A. R. Taylor, *Journal of Research in Science Teaching* **2009**, *46*, 460-475.
[4] T. R. Tretter, M. G. Jones, T. Andre, A. Negishi and J. Minogue, *Journal of Research in Science Teaching* **2006**, *43*, 282-319.
[5] G. Tsitsipis, D. Stamovlasis and G. Papageorgiou, *International Journal of Science Education* **2010**, *32*, 987-1016.
[6] T. Tretter, *Science Teacher* **2006**, *73*, 50-53.
[7] M. G. Jones, T. Andre, R. Superfine and R. Taylor, *Journal of Research in Science Teaching* **2003**, *40*, 303-322.
[8] K. Turner, E. Tevaarwerk and N. Unterman, *Science Teacher* **2006**, *73*, 58-61.
[9] H. Margel, B.-S. Eylon and Z. Scherz, *Journal of Chemical Education* **2004**, *81*, 558.
[10] M. G. Jones, A. Taylor, J. Minogue, B. Broadwell, E. Wiebe and G. Carter, *Journal of Science Education and Technology* **2007**, *16*, 191-202.

Chapter 4:

Development of Scale Assessments

4.1 INTRODUCTION

Creating effective assessments that elicit exactly the information that, helps instructors to know the level of knowledge of is probably one of the most difficult tasks that we are given. Reflecting on Piaget's learning theory, it is important to acknowledge that each student has a unique private learning experience which makes the task of developing an appropriate assessment very difficult. Everything from the students' current knowledge to their interpretation of the sentences to their misconceptions must be taken into consideration when designing the assessment. One-on-one interviews would be the most ideal situation, where the interviewer and interviewee would be able to create a dynamic conversation so that any clarification was needed could be provided. In addition, an extraction of the personal part of the learning experience could be determined by having the interviewee explain things further with follow up questions. Interviews are time consuming, thus only a small handful of students could be examined. However, using interviews to get a representative sample of student knowledge would aid in developing a better assessment that could be used for much larger samples.

As part of a larger scale study, Jones and Taylor [1] presented a trajectory of scale concept development which is meant to outline the skills that students will possess as they progress in their scale development through novice, developing and experienced levels. The trajectory could be used as a guideline for developing interventions to move students forward in their scale proficiency. Properly designing assessments so that they are timely and effective, yet still elicit accurate information about how students think and not guess, is a challenge. Ideally, individual interviews would be the best to determine where a student would fall into the scale trajectory, however, once again, this is overly laborious and impractical and it would be difficult to assess large groups of students in this manner. In this study our goal was to develop assessment tools appropriate to classrooms of all sizes. These assessments are intended to provide a meaningful picture of the students' scale understanding and identify misconceptions. In addition, because scale has been identified as an important component in science literacy, we will also determine if scale literacy is correlated to performance and success in general chemistry courses.

4.2 LITERATURE REVIEW

One way to determine what and how a student thinks has often been left to individual interviews, but they have limitations such as time for each participant. Moreover, because it isn't realistic to interview everyone, the total number of interviews is often small compared to the population. Efforts have been made to develop effective multiple choice tests; however, it wasn't until Tamir [2] in 1971 that an alternative approach to constructing multiple choice items was developed. This method used open response answers from students to create distracters, or incorrect responses, on multiple choice tests. By utilizing this method, the distracters are more realistic possible answers since uses the students' own wordings are used and therefore results in a more accurate way to test student misconceptions. Experts who write tests become better with experience at knowing some of these common errors or misconceptions and this expertise is valuable in writing test items. However, particularly with items that specifically test definitions or misconceptions, the variance of these responses can make it difficult to "guess" what and how the students are thinking. In 1988, Treagust [3] developed a framework for the development of diagnostic tests that identify students' misconceptions. This framework is made up of ten stages which are split into three broader areas: Steps 1-4: Defining the content; steps 5-7: Obtaining information about students' misconceptions; and steps 8-10: Developing the diagnostic test. Several tests have been developed for chemistry assessment utilizing Treagust's method such as the Chemistry Concepts Inventory (CCI) [4], Particulate Nature of Matter Assessment (ParNoMa) [5], and CHEMX [6], just to name a few.

Well-written multiple-choice tests can be graded quickly and effectively with regard to measuring what students know. However, the test items are often written to test one concept only and are typically clear cut and not open to interpretation. One response is correct and the remaining incorrect responses, are often the three most common errors made by students. However, format requires that these test items can be written in such a way that there is no option to take into account the degree of the students' interpretation of the content. Another way to view student misconceptions is by providing them with options or degrees of agreement or disagreement, similar to giving them a questionnaire. An example of this is the CHEMX[6] instrument which utilized a Likert scale where participants can answer using varying degrees of agreement and disagreement. Instead of putting students into black and white categories of right and wrong, the Likert scale can allow some degree of grayness or opinions to their answers. Likert scales provide interval level data while still providing a continuum for responses. Using this method for misconceptions can help tell us to what degree are they sure or unsure about a concept which provides us with better explanation of their understanding than if a student is just right or wrong. In a study by Cooper[7] using this same approach, successfully showed that this response method is effective by comparing the results of the Likert-scaled test to other assessments such as grades.

Validity is described as "the degree to which evidence and theory support the interpretations of test scores entailed by proposed uses of tests"[8]. From a simple perspective, it can be said that a "valid" assessment is one that measures what it is supposed to measure. Validity is determined by multiple methods, including experts constructing and analyzing of the test items, the use of student responses and item statistics to edit and select test items, and comparison of the assessment measurement to other valid measures.[9] The *reliability* of an assessment instrument can be defined as the consistency of its measurement each time it is used under the same set of conditions with the same group of subjects. For example, a reliable chemistry assessment instrument would (in theory) produce the same results if given to a group of students with the same abilities. For all practical purposes, because student populations are so diverse in their range of abilities, reliability testing for assessment tools is accomplished using estimation. By using both a multiple choice test and questionnaire formats, it will allow us to have a more complete view of the students' understanding of scale and the misconceptions that they may hold.

4.3 METHODS

4.3.1 OVERVIEW

The assessment development and successive testing was performed at a large doctoral urban public institution in the Midwest. The participants were enrolled in preparatory chemistry (SCI N=350, SLST N=591) or the first semester of a two semester sequence of general chemistry course (SCI N=769, SLST N=993). The test was given to the students during the first week of class on paper using Scantron forms to report their answers. The Scale Literacy Skills Test (SLST) was administered during discussion periods with a 50 minute time limit for their weekly discussion points based on completion. The Scale Concept Inventory (SCI) was given out in the first week of class and was collected in the next lecture. Extra credit points were given for returning a completed survey. Starting in the Fall of 2010, the SLST was also administered at the end of the semester online using the course management system. The SCI was given on paper during the last week of class starting in Spring 2010. Students received extra credit for completing both. In addition a group of experienced graduate students in chemistry made up our expert group (N=14). The research protocol is approved (IRB #09.047) and all data included is from students who consented via this protocol.

4.3.2 ASSESSMENT DEVELOPMENT

Two assessments were developed to analyze different areas of the students' knowledge and understanding of scale: the Scale Literacy Skills Test (SLST) and the Scale Concept Inventory (SCI).

The first assessment developed was the SLST. Two trial tests of the SLST were constructed based on the Jones trajectory [1], results of in-class activities and interviews. These items were written by myself and Dr. Kristen Murphy and vetted for both scientific content and clarity with experts in chemistry. The two 60-item tests were then trial tested with two samples (*N* = 60; *N* = 56) from a single lecture section of first semester general chemistry during the summer 2009 session. Students were given 90 minutes to complete the test. Based on the trial testing results, the items were further refined to a final test of 45 items. Item statistics[10] included both difficulty (fraction of students who answered correctly) and discrimination values (fraction of high performing to low performing students who answered correctly). Questions were selected and refined to maintain content coverage and matched items were refined based on their difficulty and discrimination. In addition, the incorrect responses were refined further to omit distracters that weren't selected at a high enough percentage and to clarify them for content. These items were implemented starting in Fall 2009 with classes of both general chemistry I (*N* = 379) and preparatory chemistry (*N* = 181). Item statistics of the final version of test are included in the supplemental material. The test is available from the author upon request.

The second assessment that was developed was the SCI, which more closely examines previously published misconceptions. The initial results of the SLST, the responses of the in-class modules and interviews revealed that another assessment was needed that directly addressed the student's misconceptions and alternate conceptions related to scale. The SCI was designed to incorporate previously published misconceptions[11] (and references therein) that related to scale which would be relevant to a first year chemistry student. Since we wanted to investigate how students responded to misconceptions of scale, the SCI contains 40 statements which are scored by using a 5-point Likert scale (5 option continuum from strongly agree to strongly disagree). Approximately two-thirds of the statements were written to elicit a positive or agree response while the remaining third were written for a negative or disagree response. This technique would help to make sure that the students were required to read each question. In addition, to verify that students were reading the questions and answering honestly, a verification item was used. The verification item was used to separate out those students who did not correctly utilize the SCI (for example, not reading the statements, not understanding the rating scale or simply entering random responses) and were therefore not included in the final analysis. Three subjective items were also included in the assessment and therefore not graded along with the verification item. The SCI was vetted with chemistry faculty to eliminate or edit any questions that may have been a source of confusion or would give us inconsistent answers. Both assessments were statistically examined for internal (test/retest) and external (ACS final exam scores) validity and reliability. The tests were designed to complement each other and be used together in what is called the student's Scale Literacy Score (SLS).

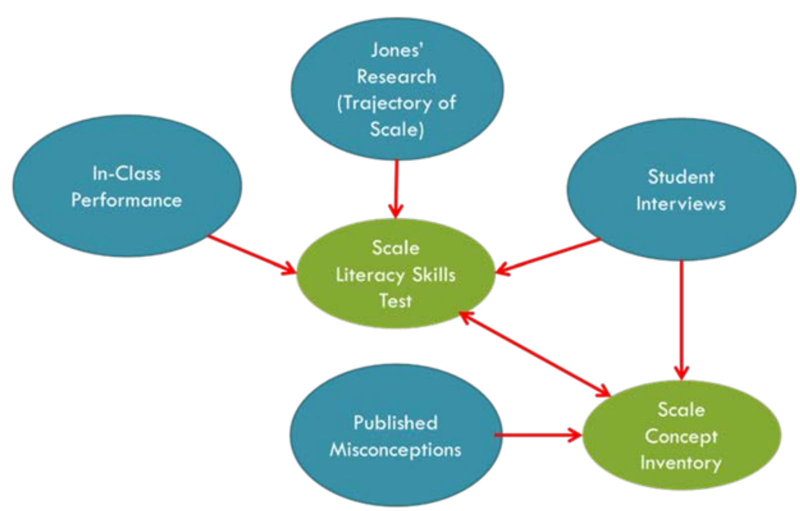


Figure 4.1 – Flowchart of assessment development.

Each of the assessments is weighted equally when calculating the SLS. Several tests (ACT, placement tests, etc.) are often examined to determine if a student will be successful in a class. Each scale assessment as well as the combined score was investigated as a potential predictor for success in chemistry.

4.4 RESULTS

4.4.1 SCALE LITERACY SKILLS TEST (SLST)

The final 45-question version of the SLST was given starting in the fall 2009 semester to both the preparatory chemistry (*N*=181) and first semester general chemistry (*N*=379) students. Each item was evaluated for both its difficulty and discrimination and the overall average for the test was also examined (Table 4.1). As shown, the groups performed similarly. The typical difficulty range for valid items on a high stakes assessment is 0.3-0.7 and above 0.25 for discrimination[10]. The difficulty and discrimination range for some items were well outside of what is normally accepted for valid items (see the high and low range on the difficulty and discrimination values). However, these items were kept specifically because they tested misconceptions. Difficulty and discrimination values on tests of misconceptions can have a broader range because they are used as a diagnostic tool[4]. A Kuder-Richardson (KR-21) analysis was performed that determines the internal consistency or reliability of the test. The equation for KR-21 is given below. A result of 0.6 or higher is determined

		Preparatory Chemistry	General Chemistry
Difficulty	High	0.901	0.900
	Low	0.033	0.095
	Average	0.432	0.505
Discrimination	High	0.577	0.600
	Low	-0.096	0.027
	Average	0.238	0.300

Table 4.1 – Fall 2009 results of SLST item analysis.

to be reliable. The KR-21 for the preparatory chemistry group was 0.67 and 0.70 for the general chemistry class.

$KR-21=1-\frac{\bar{X}\left(n-\bar{X}\right)}{ns^2}$	where $\bar{X}$ is the test mean; n is the number of items; s is the standard deviation

Because the Trajectory of Scale was a critical part of the development of the SLST, each question was categorized with respect to the trajectory and examined for performance. For example, the following question examines how well a student understands numbers, scientific notation and negative numbers; it is categorized as number sense in the Trajectory. Most of the items in the SLST were written to fit into the majority of the components of the trajectory of scale.

Which value is greater than zero but less than one?

(A) -5×10^{5} (B) -5×10^{-5}
(C) 5×10^{-5} (D) 5×10^{5}

Additionally, when the final 45 items were selected for the assessment, the coverage of these components by number of items and difficulty of these items were also considered. The remaining items were written based on the findings from the interviews where students struggled with the connection between macroscopic and particulate representations of matter as well as the definitions of macroscopic and particle properties. These items were categorized into two additional groups, not included in the trajectory.

The performance of each novice group and our expert group was then examined with respect to the categories in the Trajectory of Scale, Figure 4.2. There tends to be a

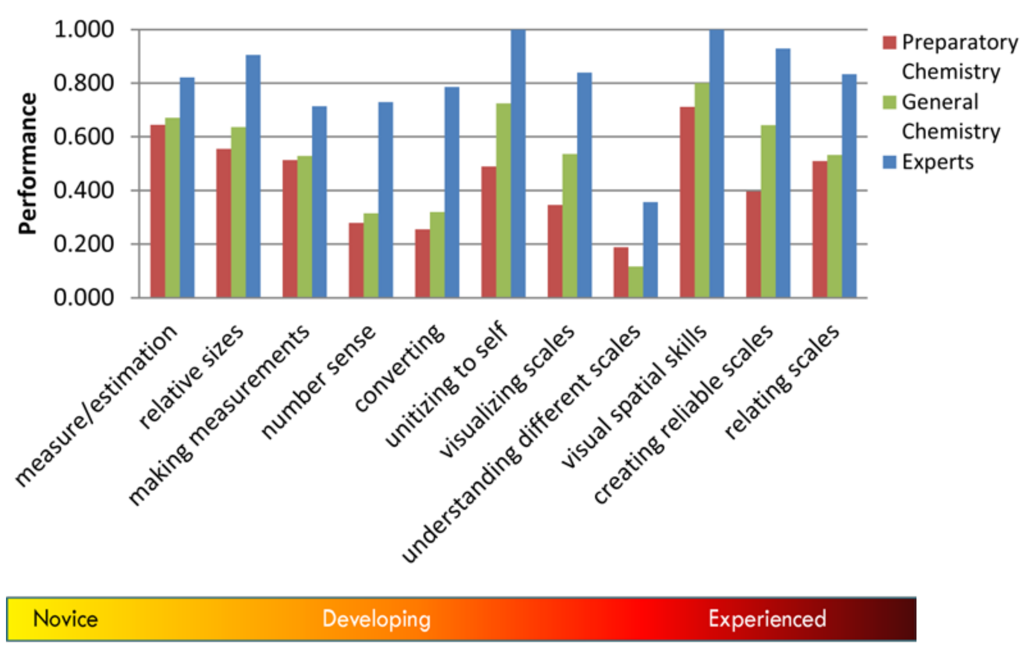


Figure 4.2 – Performance of each group on Trajectory of Scale specific items.

progressive improvement of performance from preparatory chemistry to expert levels for each area, however it is also apparent that there isn't a progressive decrease in what Jones called novice skills to expert skills. But what also can be seen that is interesting is that all groups tent to have similar areas of strengths and weaknesses.

However, when we look at the novice group and the expert group with respect to the trajectory, the experts performed substantially better on each of the areas (Figure 4.3), although even the experts weren't perfect.

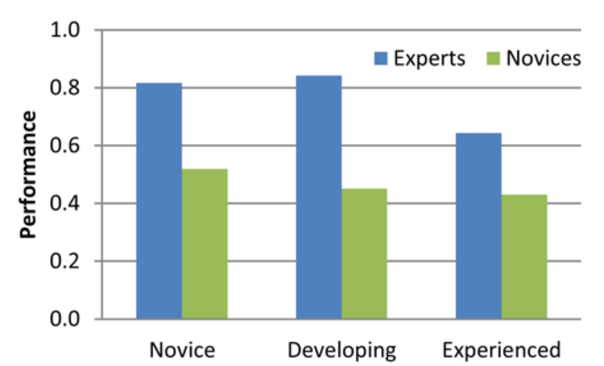


Figure 4.3 – Comparison of novice (average of preparatory and general chemistry) and expert groups in Jones' Trajectory skills.

4.4.2 SCALE CONCEPT INVENTORY (SCI)

The 40-question version of the SCI was piloted in the Fall 2009 semester (preparatory, *N*=61; general, *N*=111) and testing of the final version began in the Spring 2010 semester to both the preparatory chemistry (*N*=35) and first semester general chemistry (*N*=122) students. Any student that failed to answer the verification question correctly or didn't complete it was omitted from the study. Unlike the SLST, using the difficulty and discrimination to analyze this type of assessment wasn't appropriate; therefore other methods were used to determine the validity and reliability of the instrument. Although the misconceptions themselves were taken from the research and the interviews, experts were used to validate the content of the statements as they were written which lead to the final version of the instrument. A pre/post analysis was performed in the spring 2011 to determine the internal reliability and an ANOVA (Analysis of Variance) test was performed using the student's final grade in the class (Table 4.2).

Final Grade	Post SCI	Change (Post-Pre)	n
A	76%	7%	23
B	71%	5%	40
C	69%	4%	53
D	67%	3%	33
F*	65%	2%	9
Experts	78%	-**	21
F	8.392	3.443	
p	<0.001	0.018	

Table 4.2 – Analysis of SCI - Internal reliability using pre/post testing; External reliability using final grade. Both reliability measures are statistically significant.

A factor analysis was performed to determine if there were some commonalities with the misconception questions. After many attempts to factor the 36 remaining questions, it was quickly apparent that even though many questions contained commonalities, there was more overlap within the questions than initially anticipated (>8 factors with multiple cross loadings) and it was not pursued any further.

4.4.3 SCALE LITERACY SCORE (SLS)

Both the SLST and the SCI measure aspects of a student's conception of scale and were intentionally created to complement each other to provide a complete picture of the students' scale comprehension. Therefore a score called their Scale Literacy Score (SLS) was created by weighting each of the assessments equally. This score was compared with standardized measures for the students, ACT scores and sub-scores and a mathematics and chemistry placement exam (American Chemical Society, Toledo Placement Exam, 1992). Because only the students in general chemistry took both the chemistry and mathematics placement exam, they are only included in the analysis which included all general chemistry students in five semesters beginning with Fall 2009 through Fall 2011. A Pearson Product Moment Correlation Coefficient was used to compare to these assessments to the scores on two final ACS exams (paired exam[12] and first term conceptual exam[13]) 40 items on each and the final percent in the class. A result of 0.5 and above is considered a strong correlation and a score of 0.3 – 0.5 is considered a moderate correlation. The results of the analysis is found in Table 4.3 and all values are significant at the p=0.01 level. There were two different instructors that taught the classes during the five semesters. An analysis was performed to determine if there was any instructor bias and it was found that there was no significant difference in the correlations for either instructor which is shown in Table 4.4. In addition, the scale literacy was either the best predictor or close to the best predictor for both instructors.

	Final 1	Final 2	Final Percent
Math placement	0.439	0.427	0.279
Chemistry placement	0.500	0.504	0.368
Combined placement	0.572	0.568	0.400
ACT composite (*N*=898)	0.529	0.513	0.237
ACT math	0.491	0.483	0.267
ACT science	0.419	0.441	0.172
Scale literacy skills test	0.542	0.568	0.398
Scale concept inventory	0.371	0.441	0.241
Scale literacy	**0.579**	**0.640**	**0.476**

Table 4.3 - Common Predictors of General Chemistry Performance: Pearson's Product-Moment Correlation Coefficient, r (all values are significant at the p=0.01 level). Both of the scale assessments had good correlations, the combination of them in the scale literacy score had the highest correlation to both ACS standardized final exams and final grade. (The *N* value varied)

	Final 1		Final 2		Final Percent	
	Inst 1	Inst 2	Inst 1	Inst 2	Inst 1	Inst 2
Math placement	0.441	0.437	0.389	0.465	0.337	0.242
Chemistry placement	0.496	0.525	0.518	0.518	0.383	0.374
Combined placement	0.571	**0.589**	0.563	0.593	0.436	0.388
ACT composite (*N*=898)	0.514	0.543	0.498	0.530	0.348	0.173
ACT math	0.452	0.529	0.417	0.551	0.337	0.230
ACT science	0.430	0.408	0.448	0.437	0.245	0.129
Scale literacy skills test	0.594	0.495	0.603	0.576	**0.487**	0.338
Scale concept inventory	0.378	0.352	0.417	0.462	0.221	0.263
Scale literacy	**0.599**	0.560	**0.623**	**0.671**	0.475	**0.489**

Table 4.4 - Common Predictors of General Chemistry Performance by instructor: The highest predictor correlation for each variable is in bold for each instructor. With the exception of one, the best predictors for each instructor are scale literacy. (The *N* value varied)

4.5 DISCUSSION

Designing appropriate class-wide assessments can be a challenge. Through the use of these assessments, the importance of scale was apparent as was how much the students were lacking in their scaling abilities. Taking into account all aspects of scale and providing two assessments that complemented each other proved to be a critical piece for having a more overarching view where students are at in their scale understanding. For the Scale Literacy Skills Test, the groups performed similarly on the items in general with the average difficulty and discrimination values being in the accepted range. The difficulty and discrimination range for some items were well outside of what is normally accepted for valid items. However, these items were kept specifically because they tested misconceptions and the test is used only as a diagnostic tool. The reliability analysis found the test to be reliable for both groups. The Scale Concept Inventory was determined to be valid when compared with course grades and experts. In a pre/posttest format, it was also found to be reliable.

Common predictive measures of success in general chemistry include placement exams in math and/or chemistry[14] [15] [16] [17], standardized proficiency exams (ACT or SAT), or measures such as logical thinking or reasoning[18], conceptual math knowledge[19] or high school content knowledge[20]. Because scale has been recognized by several notable groups such as AAAS as being a critical theme that pervades throughout all areas in science it seems logical that it may be a key component to student success. It is no surprise that the correlation of the scale literacy score is so high for the ACS national exams and the final grade in the course. However these are just correlations and no assumptions can be made to a causal effect. That doesn't diminish the power of scale as a predictor for success in general chemistry but it doesn't guarantee success.

4.6 CONCLUSION

Providing assessments that encompassed all areas of understanding as well in multiple formats helps to create a much clearer assessment and therefore better measure from which to make a judgment. For many years, much importance has been placed on standardized tests and their power of predicting how a student will perform. The scores on these exams can determine whether a student gets into college or be able to take a class, but are they truly representative of the skills necessary for success? It is reasonable to assume that there are many factors that enter into a student being successful and it is entirely too complicated to guess, however it is inarguable that there are specific skills that are important to gaining a depth of understanding in a science. It is apparent that scale plays a bigger role than it has been given in the past and although these assessments don't provide a causal effect, they can provide a starting place for educators to know where their students are and therefore design their instruction appropriately. Finally, these tests can be used to test the efficacy of this redesigned instruction.

4.7 REFERENCES

[1] M. G. Jones and A. R. Taylor, *Journal of Research in Science Teaching* **2009**, *46*, 460-475.
[2] P. Tamir, *Journal of Biological Education* **1971**, *5*, 305-307.
[3] D. F. Treagust, *International Journal of Science Education* **1988**, *10*, 159-169.
[4] D. R. Mulford and W. R. Robinson, *Journal of Chemical Education* **2002**, *79*, 739-744.
[5] E. J. Yezierski and J. P. Birk, *Journal of Chemical Education* **2006**, *83*, 954.
[6] N. Grove and S. L. Bretz, *Journal of Chemical Education* **2007**, *84*, 1524.
[7] M. M. Cooper and S. Sandi-Urena, *Journal of Chemical Education* **2009**, *86*, 240.
[8] A. American Educational Research, A. American Psychological, E. National Council on Measurement in, E. Joint Committee on Standards for and T. Psychological, *Standards for educational and psychological testing*, American Educational Research Association, Washington, DC, **1999**, p.
[9] T. Holme, *Journal of Chemical Education* **2003**, *80*, 594.
[10] I. D. a. E. Eubanks, L.T. in *Writing Tests and Interpreting Test Statistics: A Practical Guide*, *Vol.* American Chemical Society (ACS), Division of Chemical Education, Examinations Institute., **1995**.
[11] V. Kind in *Beyond Appearances: Students' misconceptions about basic chemical ideas*, *Vol.* Royal Society of Chemistry, **2004**, p. 84.
[12] D. o. C. E. American Chemical Society, Examinations Institute in *General Chemistry First Term Paired Question Exam*, *Vol.* University of WI-Milwaukee, Milwaukee, WI, **2005**.
[13] D. o. C. E. American Chemical Society, Examinations Institute in *General Chemistry Conceptual Exam*, *Vol.* Iowa State University, Ames, IA, **2008**.
[14] D. o. C. E. American Chemical Society, Examinations Institute in *Toledo Chemistry Placement Exam*, *Vol.* Clemson University, Clemson, SC, **1992**.
[15] N. J. Pienta, *Journal of Chemical Education* **2003**, *80*, 1244.
[16] J. C. Legg, T. J. Greenbowe and M. J. Legg, *Journal of Chemical Education* **2001**, *78*, 1117.
[17] A. A. Russell, *Journal of Chemical Education* **1994**, *71*, 314.
[18] D. M. Bunce and K. D. Hutchinson, *Journal of Chemical Education* **1993**, *70*, 183.
[19] D. G. Leopold and B. Edgar, *Journal of Chemical Education* **2008**, *85*, 724.
[20] R. H. Tai, R. B. Ward and P. M. Sadler, *Journal of Chemical Education* **2006**, *83*, 1703.

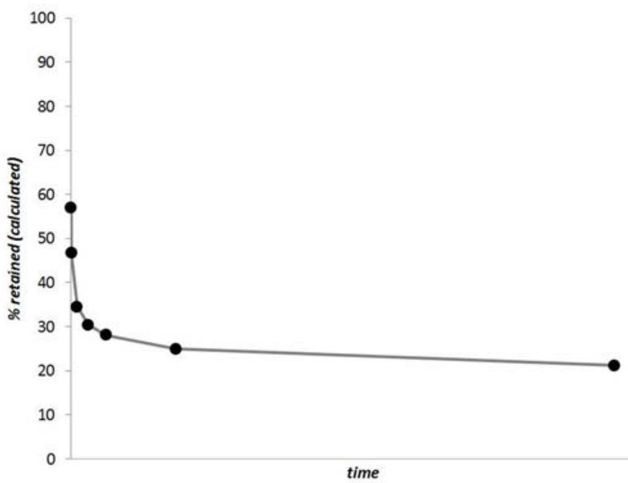
Chapter 5:

Supplemental Activities to Teach Concepts of Scaling and Macroscopic/Particle using an Adaptive Approach

5.1 INTRODUCTION

All of us have sat in large lecture halls and tried to absorb the information that is being didactically delivered. Yet, as educators, we often expect students to also absorb the information the same way. I have heard students both at the high school and collegiate levels complain that lecture doesn't help them and that it is a waste of time to sit there and listen. Lecture has been a long accepted practice, and it is just "the way things are done", yet in retrospect, this process is not the primary mechanism for learning and understanding the content. To fully understand why this falls short of teaching our students, it is important to step back and examine more closely how students learn and what it takes to learn and remember things.

In 1885, Hermann Ebbinghaus[2] experimented with how long you are able to remember things after initially learning the material. He tested learning at regular intervals, how much was retained, and how difficult it was to relearn the material. Ebbinghaus found that an exponential loss of information occurs as time goes on, also known as "The Forgetting Curve" (Figure 5.1). However, Ebbinghaus also hypothesized that basic training can help to increase the strength of memory: better memory representation and repetition based on active recall. Ebbinghaus looked at how he could improve knowledge by relearning. A factor that affects both initial and relearning is the



Time Since Learning	Ebbinghaus' Observed Data	Ebbinghaus' Calculated Data
20 minutes	58.2%	57.0%
1 hour	44.2%	46.7%
9 hours	35.8%	34.5%
1 day	33.7%	30.4%
2 days	27.8%	28.1%
6 days	25.4%	24.9%
31 days	21.1%	21.2%

Figure 5.1 - Ebbinghaus' Forgetting Curve. His observed data provided an exponential decay curve, $R = e^{-\frac{t}{S}}$, where R is memory retention, S is relative strength of memory, and t is time.[1]

type of practice. The two types of practices that are widely accepted by psychologists and educators are distributed practice, which refers to regular periods of practice (daily review), and massed practice, which refers to periods of intense practice (cramming). A quick internet search on these practices quickly reveals many experiments (some dating back to the early 1900s) comparing these methods and on the benefit of distributed practice in long-term retention. Figure 5.2 is an example of what is hypothesized to happen to Ebbinghaus' forgetting curve with distributed practice. It suggests that each practice will renew the information level and therefore prolong the retention of the material and take longer to "forget" the material.

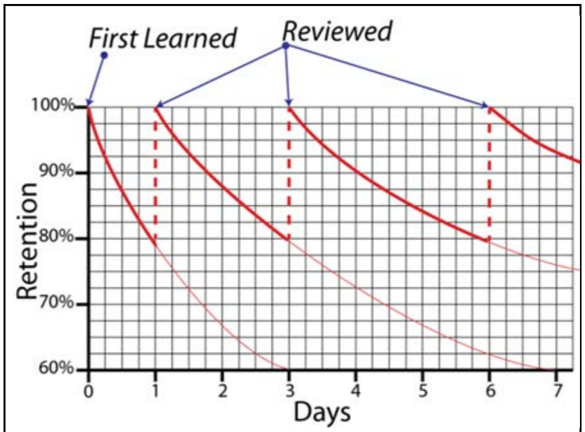


Figure 5.2 – Example of how Ebbinghaus' Forgetting Curve changes with distributed practice.

Edgar Dale looked at how the method of content delivery affected the retention of material and developed what has become known as the "Cone of

Learning” [4]. As shown in Figure 5.3, when material is presented verbally, we tend to only remember about 4-8% of the material after 6 weeks. If visuals are added to the lecture, it only increases minimally to 12-18% retention. This tells us that didactic lecture isn’t effective and, although adding visuals helps, it is of minimal benefit. Because it is unreasonable to expect the traditional didactic lecture to change overnight, it is reasonable that we address the issues by examining what can be done after the initial lesson and how it is addressed.

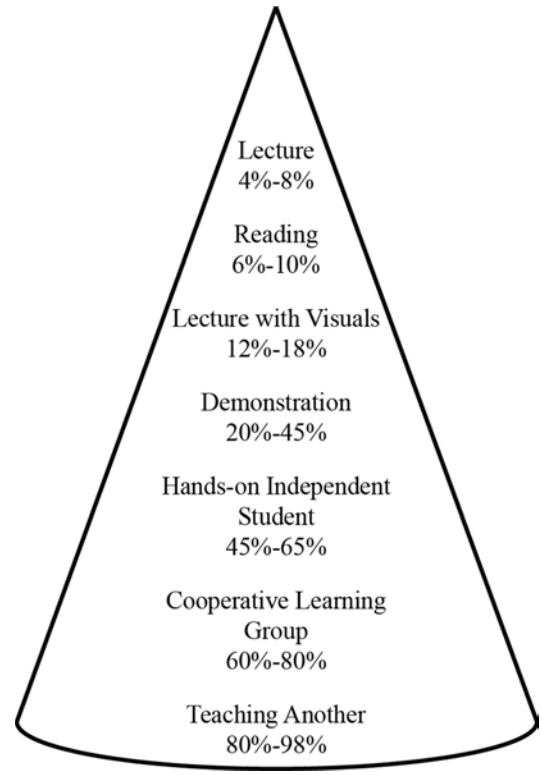


Figure 5.3 – Dale’s Cone of Learning: Percentage retention after six weeks based on method of learning.

In a study performed by Karpicke and Blunt[5], they examined how creating retrieval practice situations was a more beneficial way to learn than elaborative studying with concept mapping. From a cognitive standpoint, retrieval may create better and more

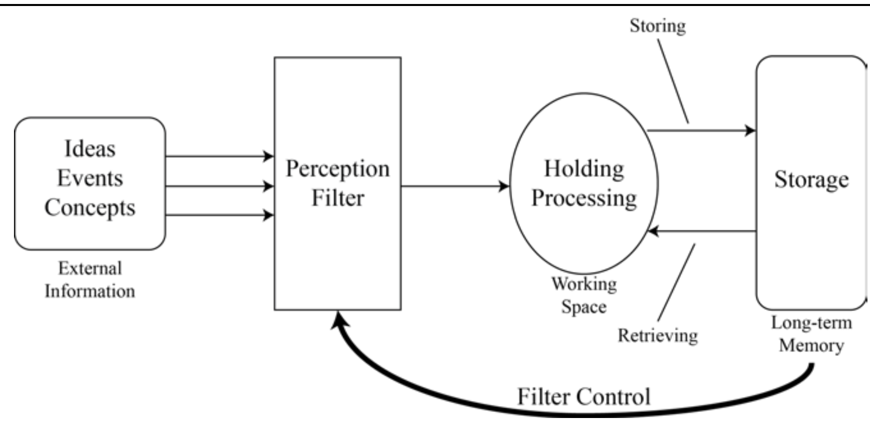


Figure 5.4 – Johnstone’s Information Processing Model based on Piaget’s theories.

concrete connections of information in our schemas. If we look at Johnstone's information processing model (Figure 5.4)[6] that incorporates parts from Piaget's theories, the retrieval process changes how the information is processed and therefore makes learning different. In addition, because retrieval is such an important part of effective practice by providing a stepping stone to connecting new material with previously stored information, it is critical to consider each student's proficiency level. Therefore, it is important that any supplemental instruction or practice isn't too easy so our stronger students are bored but it isn't so challenging that the weaker students are overwhelmed and give up. Bringing students into effective practice means to bring them in at the student's level of proficiency with common exit point/goal.

This raises two questions about what needs to be done to help students after the initial learning event.

-Would collaborative learning or individual learning be more effective?

-What should the learning structure look like of the supplemental material so that it is effective for all students?

5.2 METHODS

5.2.1 OVERVIEW

The experiment was performed at a large doctoral urban public institution in the Midwest. The supplemental instruction had two components: scale and macroscopic/particle. The supplemental instruction was conducted with a pilot study (*N*=476) that was conducted with students enrolled in preparatory chemistry (*N*=99) and the first semester of a two semester sequence of general chemistry (*N*=377) in the fall and spring semesters of the 2010-2011 academic year. A treatment/control experiment was done during the fall semester of 2011 (*N*=303 total) with students enrolled in the first semester of a two semester sequence of general chemistry (control, *n*=73; treatment, *n*=230). The research protocol is approved (IRB #09.047) and all data included is from students who consented via this protocol. Student demographic data can be found in the supplemental materials.

5.2.2 DEVELOPMENT OF INSTRUCTIONAL MATERIALS

The supplemental online instruction was designed on the school's online course management system (Desire2Learn, D2L) as a group of quizzes that have conditional releases based on the students' scores and therefore organized as a hierarchy of performance. There were two online supplemental activities that students took: scale and macroscopic/particle. Each student started by taking a quiz consisting of 10 initial questions. These were questions from the Scale Literacy Skills Test, in-class clicker

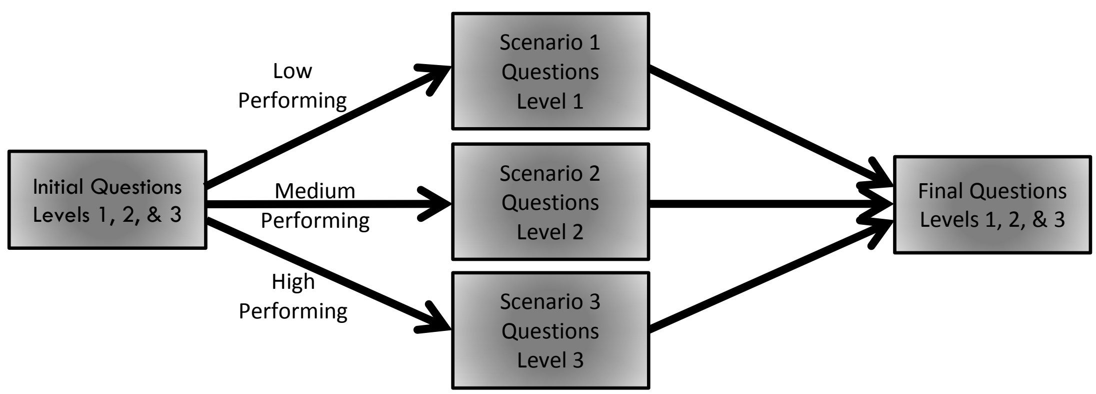


Figure 5.5 – Question organization

questions, and clones of both question sets. The questions were divided into three performance levels based on the scale concept trajectory by Jones [3] and therefore their scores were weighted based on these levels, see Figure 5.5. The students' scores determined at which scenario they began. This ensured that a student who was able to answer level 1 questions would be appropriately placed in the correct scenario based on their abilities (and in this case, level 1). These questions were also representative of the skills that were presented in the scenario levels. Therefore the questions that were categorized as difficulty 3 were aligned with the skill set for Scenario 3. Another set of final questions were required for them to finish the activity. These final questions were also weighted by difficulty so as to be able to compare to their performances. Based on their scores on the initial questions the students were piped into one of three scenarios. If a student is placed into the lowest performing scenario, they will need to work through all three scenarios in order to complete the module. The pathways and required percentages are shown in Figure 5.6.

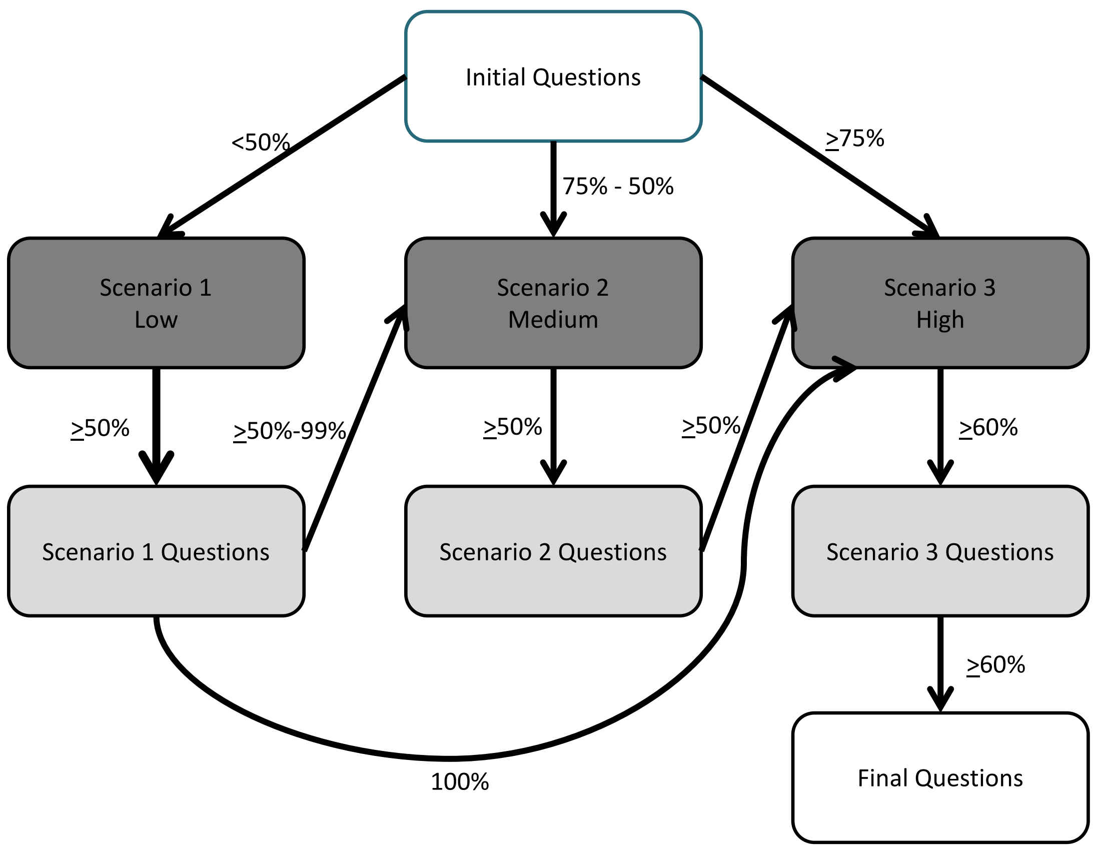


Figure 5.6 – Online supplemental instruction quiz pathways and conditional release requirements.

Scenario 1 is a mirror of the in-class module. It is geared towards students that are at the lowest level of proficiency. The reason for mirroring the in-class module was that if students were either absent for the module or did not learn the material presented in the module, this was the learning opportunity for them. It was presented as a skills practice

Novice	Developing	Experienced
• Developing measurement and estimation skills • Conceptualizing relative sizes • Using measurement tools skillfully • Development of number sense	• Converting measurements and scales • Surface area to volume relationships • Being aware of changing scales • Using body rulers for measurement and estimation • Visualizing scales • Understanding different types of scales • Development of proportional reasoning: Visual spatial skills	• Automaticity and accuracy • Creating reliable scales • Relating one scale to another • Developing accuracy in using scale • Applying conceptual anchors when estimating scale

Table 5.1 – Jones Trajectory of Scale Concept Development[3]

that is based on Jones' novice trajectory, Table 5.1. At the novice level, the skills include developing measurement and estimation skills, conceptualizing relative sizes, using measurement tools skillfully and development of number sense. Hints were provided to aid students and images from a scanning electron microscope (SEM) and scanning tunnelling microscope (STM) were accessible throughout the activity.

After completeing the scenario and earning a score of at least 50% or higher (with some questions graded on completion and not performance), the students were required to take Scenario 1 final questions that were cloned questions of level 1 initial questions. The questions were based on the skills that were practiced in the scenario. This was the assessment that they were successful at the lowest proficiency level. If the students did not score a 50% or higher on these questions, they repeated the scenario, final questions, or both until they received a passing score. To avoid the probability of students attempting to game the system by repeatedly taking the test to find the answers, the question bank from which the questions were drawn was large with multiple clones of items from the various sources. Once the required score was met, the Scenario 2 quiz would become available. Students were allowed to retake the scenario and scenario final questions as many times as they wanted.

Scenario 2 was an original task that the students had not practiced earlier. It was geared for a medium level of proficiency which were skills based on Jones' developing trajectory, Table 5.1. These include converting measurements and scales, using body rulers for measurement and estimation, visualizing scales, and development of proportional reasoning using visual-spatial skills. Hints were once again provided throughout the scenario, and they could repeat the scenario as many times as they wanted. The Scenario 2 questions were medium proficiency questions that were based on the skills practiced in the scenario and were clones of the level 2 initial questions.

Scenario 3 is an inquiry activity where the student is required to apply their skills in a real-life type scenario. This scenario tests at the highest level of proficiency by working on the skills outlined as experienced on Jones' trajectory, Table 5.1: creating reliable scales and relating one scale to another. Hints were again provided for the students. The scenario 3 questions assessed for a high level of proficiency by being based on skills practiced in the scenario and were clones of the level 3 initial questions.

After working their way through the scenarios, students were required to answer a set of final questions. These questions encompassed all levels of proficiency and were clones of the initial questions. Students were able to take unlimited attempts but by completing this quiz once, the entire activity was considered completed. Therefore, very few students took the final questions more than once.

During the pilot run, students worked the activities in discussion sections conducted in a computer lab. The discussion sections were randomly divided into two groups: 1) students worked as collabortative groups and 2) students worked individually. All successive implements of this instruction was given outside of class and control for group or individual work was not controlled, however in order for students to obtain a grade, they needed to complete the activities themselves.

5.3 RESULTS

The supplemental instruction was designed especially to help the lower performing students improve their scale literacy; however, it was important that the additional instruction did not induce expertise reversal effort for the high performing students.[7] There were two supplemental instruction units: Scale (SI unit 1) and Macroscopic/Particle (SI Unit 2). To determine the "high" and "low" performing groups, we took the top and bottom half based on their scale literacy scores. As shown in Figure 5.7, both the high and low performing students had a statistically significant increase in their performance in their initial and final questions for each of the supplemental instructions and they also had a statistically significant increase in their performance on the scale literacy assessment.

The total number of attempts was also examined between the two performance groups. Looking at each of the activities within the supplemental modules, there is not a statistically significant difference in the

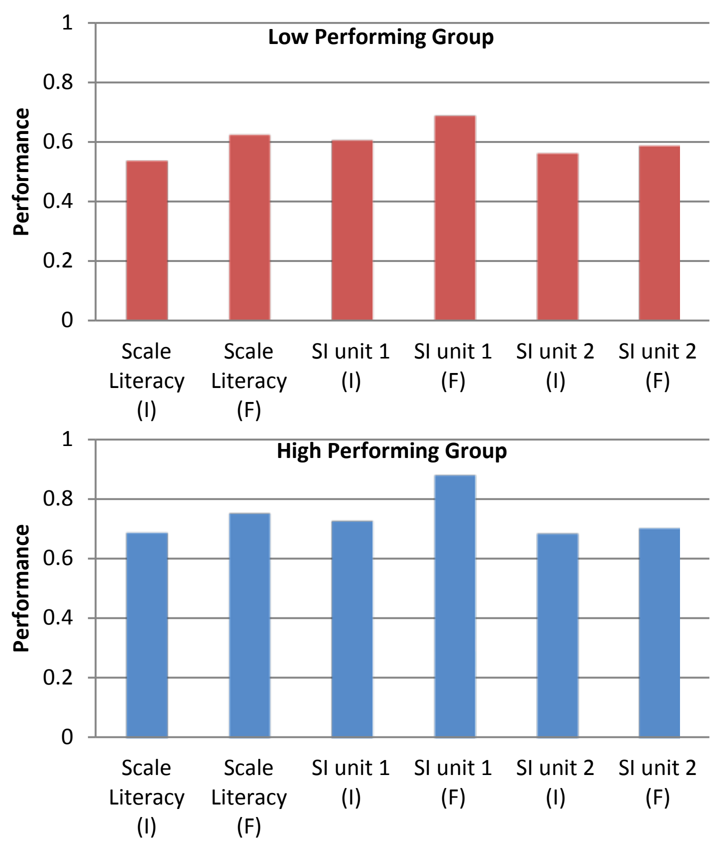


Figure 5.7 – Results of supplemental instruction (SI) and scale literacy both initial (I) and final (F). Low performing group (n=72) and high performing group (n=50)

number of attempts of the two performance groups as seen in Figure 5.8.

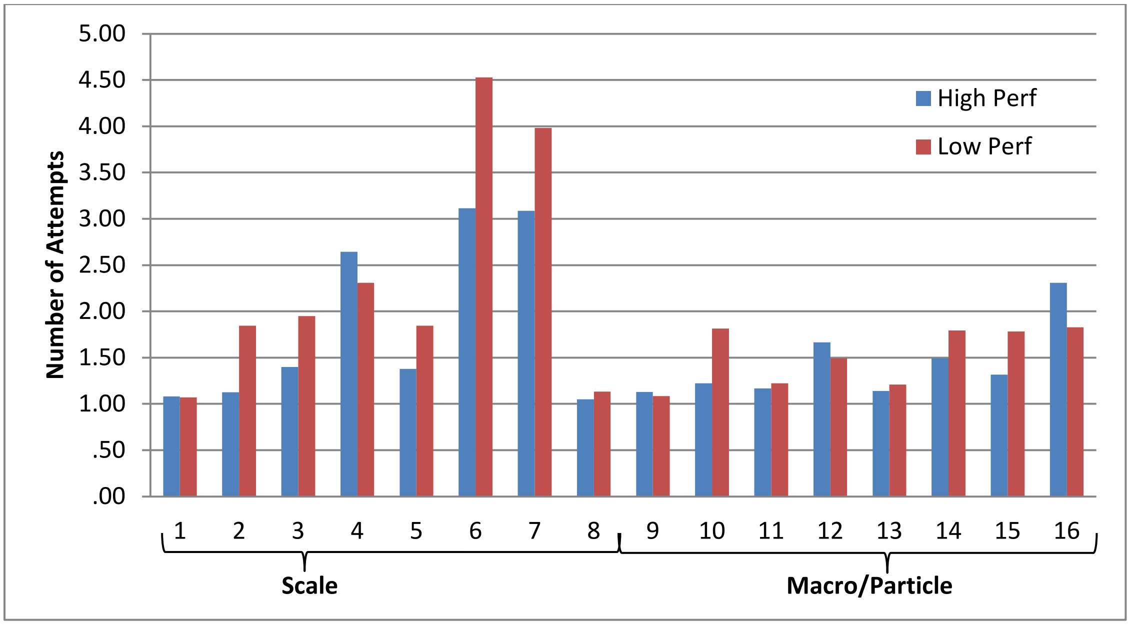


Figure 5.8 – Comparison of student performance group versus number of attempts per activity. (1 & 9 are initial questions and 8 & 16 are final questions.) Quizzes 1 & 9 only allowed for 1 attempt, however, due to the conditional releases not being set correctly in Fall 2010, some of the students were required to redo them.

During the initial experiment, discussion sections were randomly chosen and the supplemental instruction was implemented in two forms: 1) collaborative small groups and 2) individual. The groups pre-scale literacy was used to determine equivalency for the two groups, which turned out to have a statistically significant difference (p=0.009), which meant that the collaborative and individual groups were not equivalent. By comparing their post scale literacy to their pre scale literacy, the individual group had a statistically significant gain in their scale proficiency. In addition, the collaborative group also had a statistically significant gain in their scale proficiency, but when comparing the two groups post scores, there is no longer a statistically significant difference between the groups (Figure 5.9).

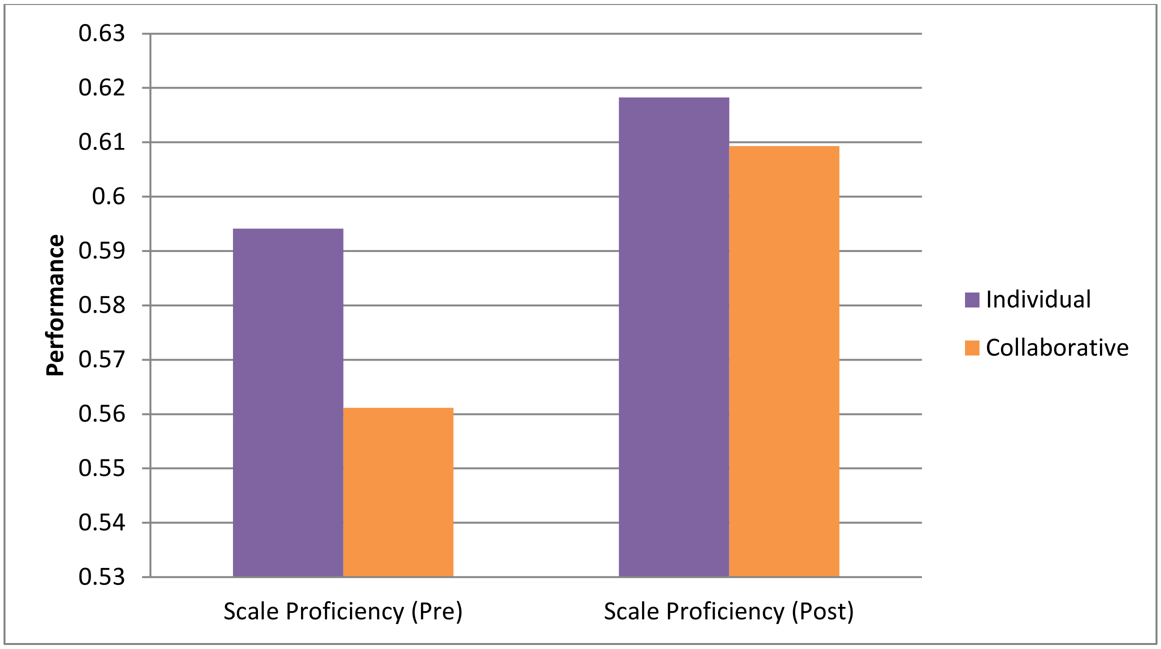


Figure 5.9 – D2L Supplemental Instruction: Collaborative Learning Groups vs. Individual Learning

In our previous semesters of implementing the supplemental instruction, all test groups were exposed to it and there wasn't a true control group that had not been exposed to the supplemental instruction. In the fall semester 2011, a control experiment was performed where one group was taught using all of the intervention materials and the other group was only tested at the beginning and end of the course with the assessment and did not receive any of the interventions.

Because the initial and final questions of each activity are clones of the actual scale literacy assessments, looking at the class performance of these initial (pre) questions as compared to the final (post) questions can provide an internal measure within the group. As can be seen in figure 5.10 , the treatment group had statistically significant gains on those questions. When we look at the scale literacy measurements of our two classes, the treatment and control groups are equivalent. After the treatment, although both groups had a statistically significant gain (Figure 5.11) , the gain for the treatment group was higher, and our groups were no longer considered equivalent. In addition, the initial and final change is statistically significant for all groups(Figure 5.12). When looking more closely at our high and low performing groups, it is quite apparent that the supplemental instruction was not detrimental to either group and actually provided both groups with positive gains in their skill literacy.

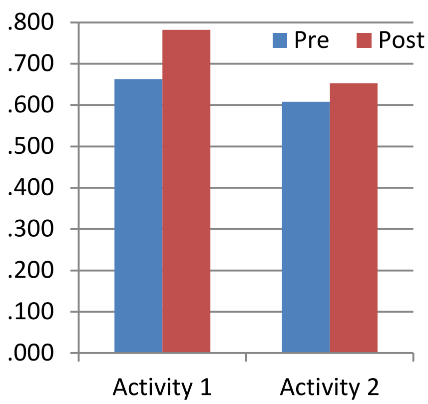


Figure 5.10 – Treatment group comparison of initial and final questions.

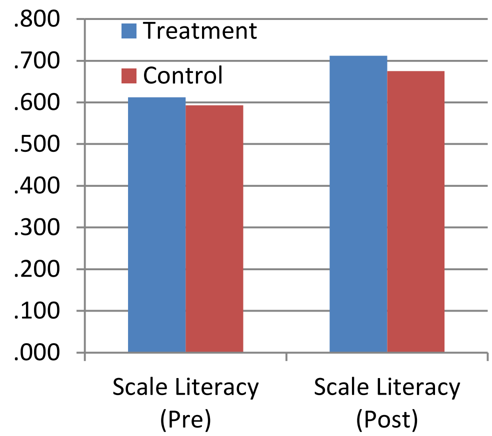


Figure 5.11 – Initial to final change comparison for treatment (n=230) and control (n=73) groups.

****Analysis only included those students who completed all components of the study and supplemental instruction units (n=230); control (n=73)**

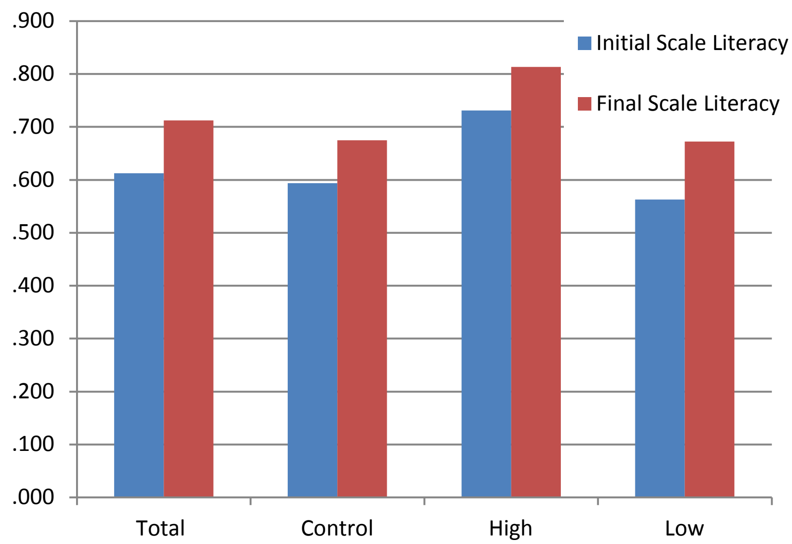


Figure 5.12 – This graph shows the results for all of the students, the control group and then the treatment group has been broken out into the high and low performing groups.

In order to get feedback from the students who utilized the adaptive exercises they were given a short survey and also provided an opportunity to leave comments at the conclusion of the semester. Students were requested to complete the survey following the final Scale Literacy Skills measure which was administered on D2L. Students were not given points for completing the survey and only those who attempted some component of the D2L activities were asked to complete the survey. Using a 5-point Likert scale, students responded to four statements:

1. The online Scale and Macroscopic/Particle Activities were challenging.
2. I learned a lot working the online Scale and Macroscopic/Particle Activities.
3. Working the online Scale and Macroscopic/Particle Activities helped me better understand the concepts in this class.
4. The online Scale and Macroscopic/Particle Activities were fun.

Combining the agree (strongly agree and agree) and disagree categories (strongly disagree and disagree), the results are shown in Figure 5.13. Between Fall 2010 and Spring 2011, 392 students completed the survey. For the first three statements, the students overwhelming agreed the activities were challenging, helped them to better understand concepts in the class and that they learned a lot working the activities. Due to the instructional nature of the activities, it was not surprising that 40% of the students did not find the activities fun. An additional 256 comments were submitted by students. Of these, 56% were positive with an additional 15% that were neutral. The majority of the neutral comments sited the inability to see figures that was due to issues with the classroom management software set-up and was quickly addressed. The majority of the negative comments were either due to the length of the activity or the lack of seeing the correct answers once they submitted their answers. Because students needed to learn from the instructional portion of the activity, if the correct responses had been shown to the students, the students would have known them and proceed to the next level without understanding the concepts presented within that level.

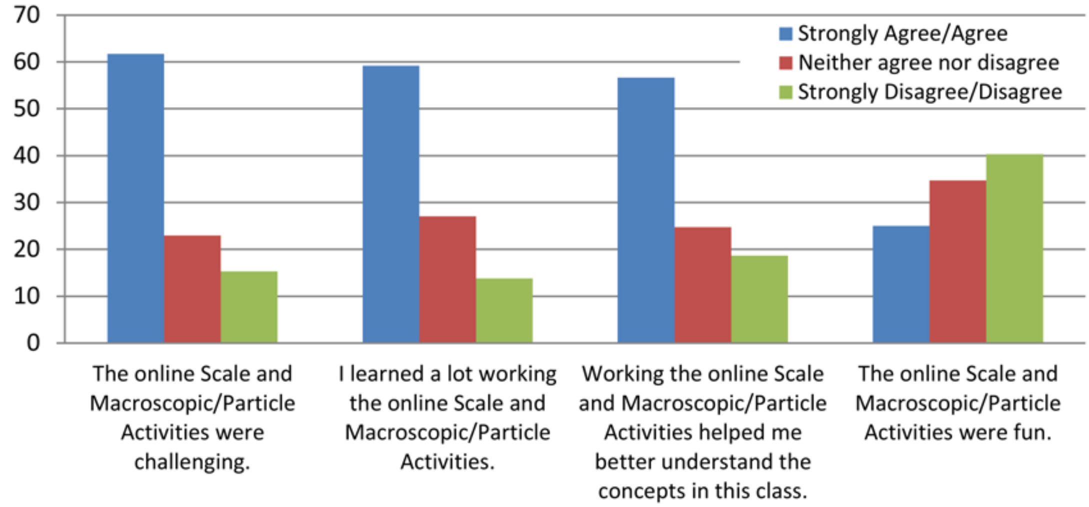


Figure 5.13 - Survey Results – D2L Supplemental Instructional Activities.

Some examples of positive student comments are:

- They seem to be helpful and they help me realize that I don't really recognize sizes of molecules.
- I found I do not fully understand scaling as well as I thought. This and similar activities are good activities to keep reinforcing these skills.
- These activities were challenging but I can begin now to understand the difference between big and small. I’m so used to learning about things that are relative to my size and what we can see.
- It was nice to spend the extra time on this topic, since for most classes it's assumed one already has a very good understanding of scale.
- The online activities were helpful and I recommend the use for future chemistry students.
- Online activities does help because it made me realize difference between particle, atom, and molecule.
- It is helpful especially conversion factors and help me realize how small an atom, molecule and bacteria is.
- It was interesting and helped to put a lot of what we do in class into real life perspective. Size wise I feel a lot more competent as to how big or small something is.
- A lot of the questions appear self-explanatory, but I didn't realize how deceptive scale can really be.
- Showed that I understood the macroscopic topics much easier than the microscopic.

- As with any portion of the class, it helps a lot to work with others. One portion of the scale activity, I could not complete a passing attempt. I worked with a friend and she pointed out that I was dividing the wrong number (I had them flipped in the fraction). It took someone else pointing this out to realize I had done it, I won't do it again. I would mention maybe working with someone else to help increase your learning experience.

5.4 DISCUSSION

The supplemental instruction was able to provide the needed practice for students to improve their scale literacy. Providing students with a differentiated practice showed that we were able to improve the skills of both the high performing group and the low performing group. As was seen in the control/treatment experiment, even the control group had an increase in scale literacy due to other factors, possibly experienced through learning course content. As the course instructor for both classes (treatment and control) were the same and the course instructor invariably stressed the importance of scale and scale-related concepts through regular instruction, examining another course instructor for a control group is warranted. This analysis is underway in the next phases of this project.

More importantly, the treatment group experienced a greater gain in scale literacy, presumably through the specific instruction on scale. The difference in the means of the final scale literacy score for the treatment group versus the control group was statistically significant, meaning we created a significant difference in the means of the groups and they were no longer equivalent, indicating that the intervention caused a positive effect on scale literacy. In addition, during the pilot study, it was apparent that the collaborative groups benefited even more than the students that just did it as individuals. This could be explained by the memory theories given previously. In Figure 4.3, Dale recognized that collaborative group learning and teaching someone provided the greatest retention of material as measured after 6 weeks[4]. When we examine the low performing group, they were able to be taught and helped by stronger students. When low performing students worked alone, it is more likely that they would have struggled more and possibly even have given up. The higher performing students provided explanations and connections that the lower performing students required. In addition, this symbiosis of performance levels provided the higher performing students with the memory benefit of teaching someone else, which according to Dale, provides a 80-98% retention. In addition to just seeing that the students were statistically more successful, they were also able to report that they were challenged and were able to learn the material.

5.5 CONCLUSION

Creating a supplemental instruction that took into consideration the student performance levels was critical in providing a meaningful learning experience. Using an initial measure to tailor instruction better facilitated the learning or practice event for longer retention. Understanding the cognitive basics for learning, it is apparent that much more thought needs to go into developing retrieval practices that help students to think about the material and make connections that they wouldn't normally have done. Providing students with these experiences not only helps them with their understanding, but also has a strong impact on their long term retention of the material because the student is actively involved rather than just passively reading. Finally, it is crucial that instructors don't overlook the benefits of collaborative group learning. This simple technique showed that it was able to benefit both the high and low performing groups in a positive way.

5.6 REFERENCES

[1] H. Ebbinghaus in *Memory: A Contribution to Experimental Psychology*, *Vol.* Teachers College, Columbia University, New York, **1885**.
[2] R. H. S. Bruning, Gregory J.; Norby, Monica M.; Ronning, Royce R., *Cognitive Psychology and Instruction*, Pearson Prentice Hall, **2004**, p. 426.
[3] M. G. Jones and A. R. Taylor, *Journal of Research in Science Teaching* **2009**, *46*, 460-475.
[4] T. Lord in *Revisiting the Cone of Learning*, *Vol. 37* National Science Teachers Association, **2007**, pp. 14-17.
[5] J. D. Karpicke and J. R. Blunt, *Science* **2011**, *331*, 772-775.
[6] A. H. Johnstone, *Journal of Chemical Education* **2009**, *87*, 22-29.
[7] S. Kalyuga and J. Sweller, *Journal of Educational Psychology* **2004**, *96*, 558-568.

Chapter 6:

Conclusion

This study set out to positively affect the students by exposing them to new scale based lessons and an opportunity to interact with live instrumentation; however, it was quickly apparent that moving between scaled worlds was a greater challenge for them than originally thought. Students in introductory chemistry have a deficiency in both relative and absolute scaling, particularly as these sizes get farther from human size. In addition, the students have such a varying range of proficiency that it makes it difficult to specifically address certain items. Students tended to have difficulty in anchoring to new sized worlds and showed little evidence of anchoring to the molecular level. This suggests that students have not developed or used the skills to scale beyond the visible realm. The skill of anchoring is critical in helping students move efficiently between differently scaled worlds particularly small sizes which are critically important in chemistry. Within the more experienced group, their performance was considerably better, and it was obvious that during their extended time in the field of chemistry, they have developed some of the skills and perception in the areas of scale and unitizing, therefore more time needs to be spent exposing our students to the differently scaled worlds as well as providing them with the necessary tools to move between them.

With our technological world moving further from the human scale, it is essential that students begin to understand the world around them beyond what is visible. Even though this preliminary study shows that utilizing instrumentation and inquiry is important, scale needs to be considered as an inclusion curriculum wide rather than a 1 or 2 day event. It will be critical to develop not just a couple of lessons or a unit on scale but develop a curriculum with scale as a continuous theme. Providing learning experiences for students in class is essential and being able to efficiently measure the effectiveness of the material is critical to keeping our students moving forward in their understanding. A spiraling approach to scale is important to consider so that long term understanding can be maintained. Using appropriate initial assessments will also provide a better idea of proficiency and will enable instructors to choose more appropriate lessons and focus on the skills that are yet to be developed.

Tailoring interactive supplemental instruction that took into consideration the student performance levels was critical in providing meaningful learning experiences and better facilitated the learning process. Providing students with additional experiences not only helps them with their understanding, but also has a strong impact on their long term retention of the material because the student is actively involved rather than just passively reading.

Scale is a complicated topic and this study has only sought to determine some of the issues regarding it, however, the causal effect is far beyond the abilities of these preliminary findings. It is obvious that it is important to a student's understanding and success in the chemistry field, but it is a difficult task to determine what is at the heart of the issue.

APPENDIX A: INTERVIEWS

Interviews were set up to run between 30 and 60 minutes in length. Each interview has a protocol that was followed which helped to avoid bias in the process. Participants were asked to questions on items that they were correct on as well as ones that were incorrect. Participants were made aware that questions were not to be construed as a cue for an incorrect response.

Scale Interview

For parts 1, 2, and 3; stacks of 3 cards were made on cardstock paper for each item in the following order; name only, name only, name with measurements, and paper clipped together. For part 4, print the number line and tape together. A stack of copy paper is also needed for creation of the bins (be sure to have ample amount so as not to limit the student.)

Unitizing/Anchoring Interview

Print the cards with a colored printer on cardstock and cut them out. Have a magnitude continuum that extends from >+9 magnitudes to <-9 magnitudes (this can be done using headers on standard sheets of paper). Print out copies of the comparison drawings (phase 1, baseball stadium/ball, plant cell/water, buckyball/carbon atom/water molecule; phase 2, Earth/?, hair/cell, large molecule/water molecule).

PROTOCOLS

These are the scripts that were read from for each participant. All attempts were made to make sure that each participant had similar treatments. Any variations to these were on a participant basis (additional clarifications, questions about particular items, etc) and did not affect the outcome of the interview.

Scale

This interview will be videotaped. Please speak your way through your processes (ie, give reasons for changes). There are 4 parts to this interview. You may ask questions, however, my responses will be limited to guiding answers. This interview is meant to be a free response so that we may see how students think about this concept and what reasoning ability they exhibit. There are no wrong answers and you should not feel pressure to answer a certain way. You may stop your interview at any time.

Part 1 – Bin Sort

In this part, I would like you to use the 20 items (stacks of cards) and create bins, using pieces of card stock, to organize them by size. You may create as many bins as you would like. You are encouraged to create several bins. Please organize your bins with smallest on the left and largest on the right. Once you have placed all of the items, please remove the top card from the stack and give them to me.

Part 2 – Organizing within the Bin

In this part, I would like you to organize within your bin by size. Please put them in a column with the smallest at the top. At this time, you may transfer items to other bins as you see fit. Once you are satisfied, please pull the top card from each stack (smallest on top) and hand it to me.

Part 3 – Organizing with Extra Info

In this part, I would like you to reevaluate your placement of the items using the extra information that is given on the cards. Once again, you may transfer items as you see fit. Once you are satisfied, please pull the top card from each stack (smallest on top) and hand it to me.

Part 4 – Number Line

I will lay a number line in front of you. You will need to define the unit used for the number line. Using the items with the sizes on them, place them above and below the number line at their appropriate spots. Finally, I will give you 2 strips of 2 colors of cardstock. Use the blue strips to mark the boundaries of normal unaided human sight. Use the yellow strips to mark the boundaries of current technology aided sight.

Final Questions –

Which task did you find the most difficult? Which was the easiest? Why do you feel that way?
Was it easier to sort the larger or smaller objects? What made it easier?
Was there a particular range of sizes that was easiest? Why?
What was the most difficult unit to use? The easiest?
On a scale of 1-10, with 1 being easy and 10 being hard, what was your level for placing the cards on the number line?

Unitizing/Anchoring

This interview will be videotaped. Please speak your way through your processes (ie, give reasons for changes). There are 5 parts to this interview. You may ask questions, however, my responses will be limited to guiding answers. This interview is meant to be a free response so that we may see how students think about this concept and what reasoning ability they exhibit. There are no wrong answers and you should not feel pressure to answer a certain way. You may stop your interview at any time.

Part 1 – Sort to Scale

In this part, I will give you 20 objects that have a scale associated with them. I would like you to create 2 piles comparing the image to actual size. Please place each of the cards on either the bigger or smaller categories.

Part 2 – How much bigger?

In this part, I would like you to determine how many orders of magnitude you would need to increase or decrease by to get the object to its actual size. I will show you using the stamp and pencil as an example.

Part 3 – Comparison with Unitizing

In this part, I will be giving you 2 pictures and asking you to draw another object in comparison to the object pictured.

1. Miller Park, draw a baseball in comparison to Miller Park
2. Plant Cell, draw a water molecule in comparison to the Plant Cell

Part 4 – How many?

In this part, I would like to you to record how many baseballs would fit across Miller Park. Then I would like you to repeat the process for how many water molecules you feel would fit across a cell?

Part 5 – Comparing Molecules

In this part, I would like you to draw a water molecule in comparison to the molecule that is given. Then determine how many water molecules would be the same length as the molecule pictured.

Final Questions –

1. Referring back to the measuring of Miller Park, what object would be a better unit for measuring? Why did you choose that object?
2. Now looking at the cell, what object would be a better unit for measuring? Why did you choose that object?
3. Refer back to the magnitudes; briefly describe mathematically how you would determine the magnitudes (atom, football field, nucleus, Earth)?

Is there anything else that you would like to share about your experience that would help us better understand your comfort or struggles with this concept.

Scale Cards – Phase 1

Cell	Semi Truck
Atomic Nucleus	Bacterium
Textbook	Virus
New Pencil Length	Earth diameter
Finger	Earth to Moon

WI State width	Cruising Altitude of a 747 Jet
Football field	Adult height
Hair Width	Ant
Earth to Sun	NY City to LA
Postage Stamp	Atom

Cell 7 µm	Semi Truck 20 m
Atomic Nucleus 10 fm	Bacterium 1 µm
Textbook 28 cm	Virus 100 nm
New Pencil Length 21 cm	Earth diameter 13 Mm
Finger 8 cm	Earth to Moon 384 Mm

WI State width 450 km	Cruising Altitude of a 747 Jet 11 km
Football field 91 m	Adult height 2 m
Hair Width 100 µm	Ant 2 mm
Earth to Sun 146 Tm	NY City to LA 4800 km
Postage Stamp 1.5 cm	Atom 100 pm

Scale Cards – Phase 2

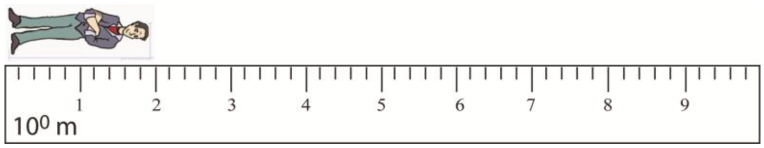
proton	diameter of sun
water molecule	yeast cell
sperm length	deer tick
width of optic fiber	silver nanotriangle
granulated sugar	dime diameter

postcard length	football length
doorway height	telephone pole
10 story building	width of Miller Park
altitude of International Space Station orbit	Milwaukee to Orlando, FL
Earth circumference	diameter of moon

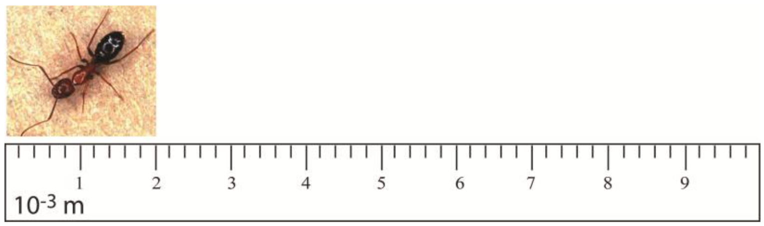
proton 2×10^{-14} m	diameter of sun 1.4×10^{9} m
water molecule 2.75×10^{-10} m	yeast cell 1.0×10^{-7} m
sperm length 8.5×10^{-5} m	deer tick 3×10^{-3} m
width of optic fiber 5×10^{-4} m	silver nanotriangle 10^{-7} m
granulated sugar 300 µm	dime diameter 10^{-2} m

postcard length 1.4×10^{-1} m	football length 28 cm
doorway height 2.0×10^{0} m	telephone pole 6.1×10^{0} m
10 story building 3.4×10^{1} m	width of Miller Park 3.3×10^{2} m
altitude of International Space Station orbit 3.5×10^{5} m	Milwaukee to Orlando, FL 1.7 Mm
Earth circumference 4×10^{7} m	diameter of moon 1.7×10^{6} m

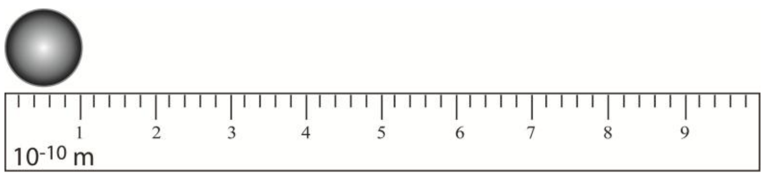
Unitizing/Anchoring Cards – Phase 1



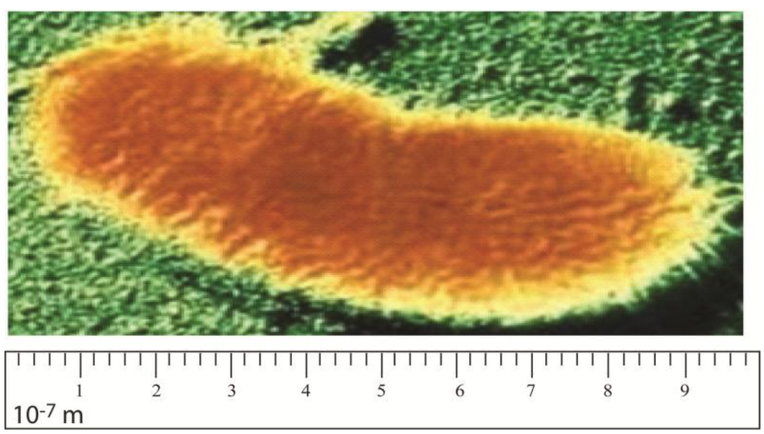
Adult



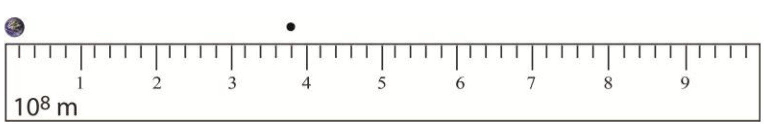
Ant



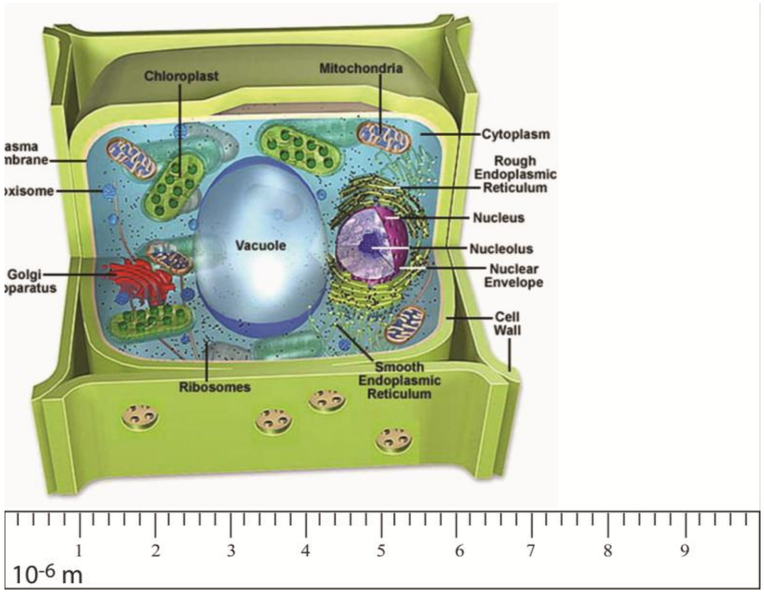
Atom



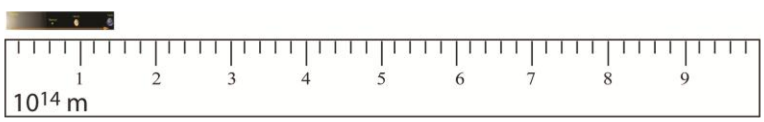
Bacterium



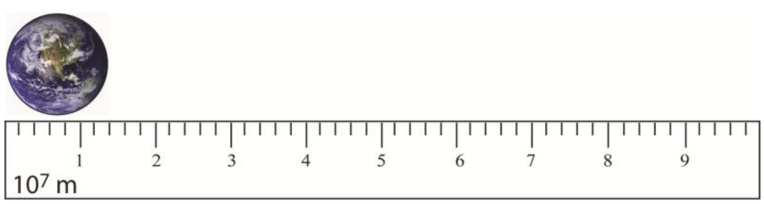
Earth to Moon



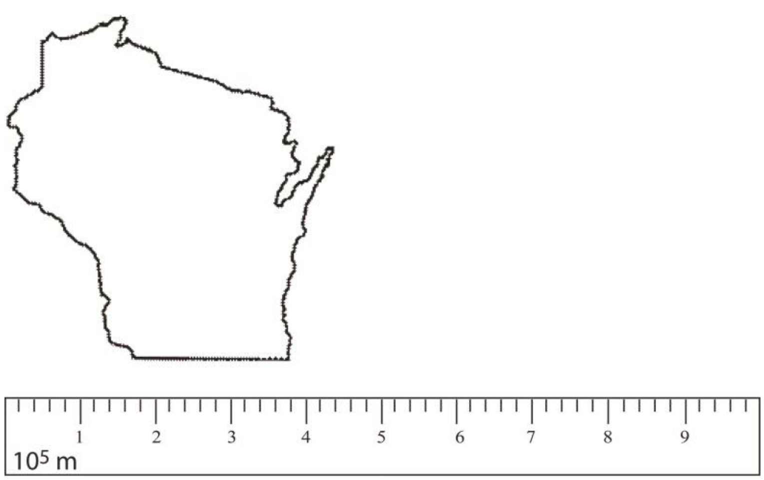
Cell



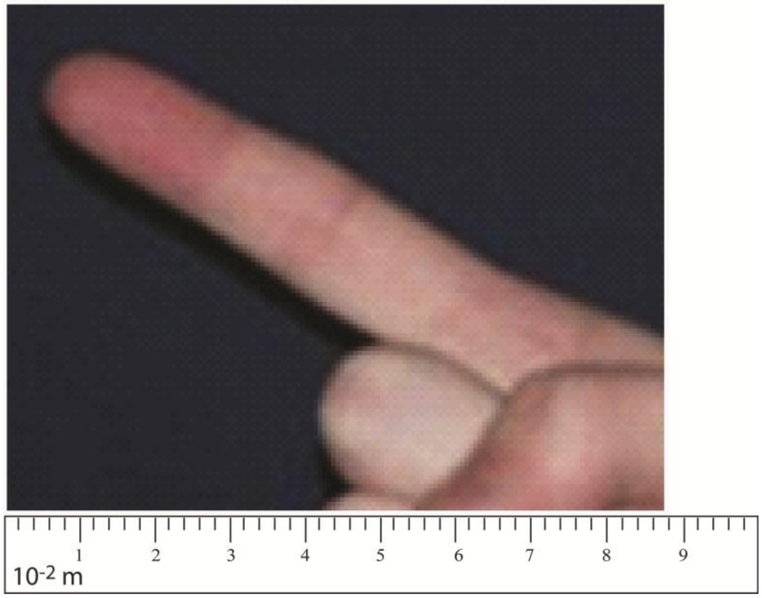
Earth to Sun



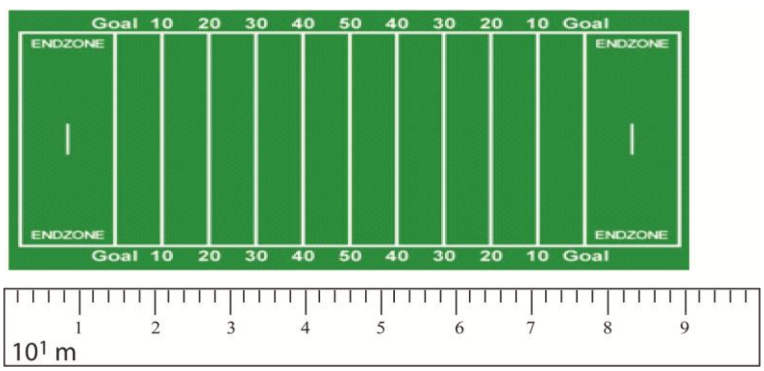
Earth



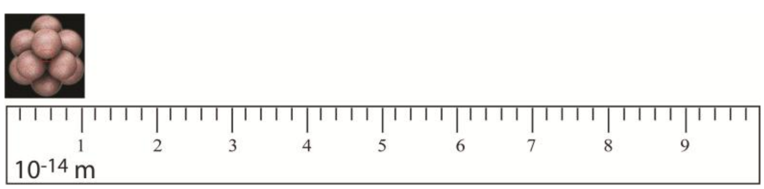
Width of state of WI



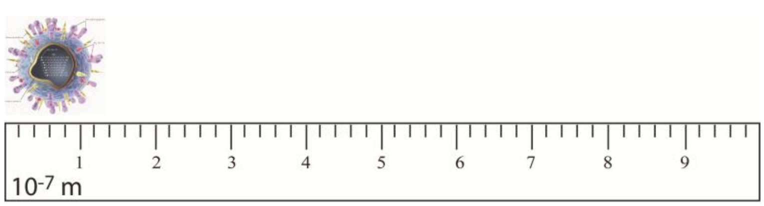
Finger



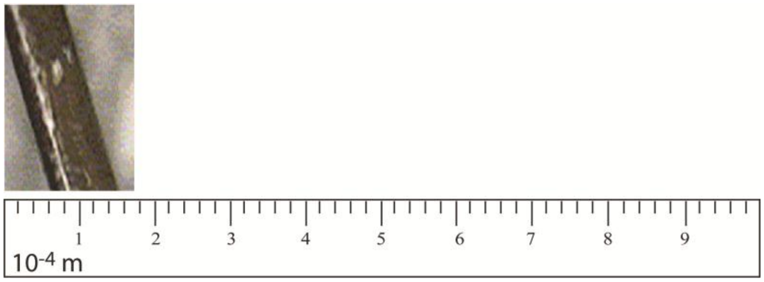
Football field



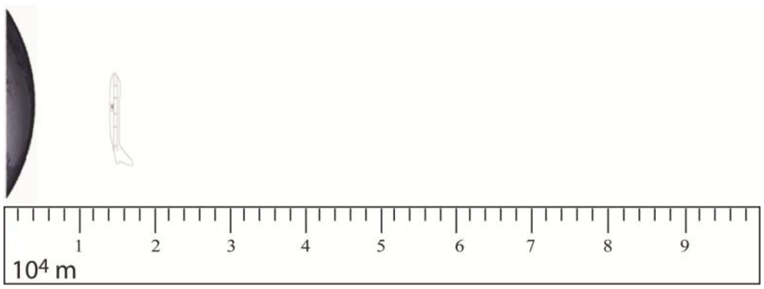
Atomic nucleus



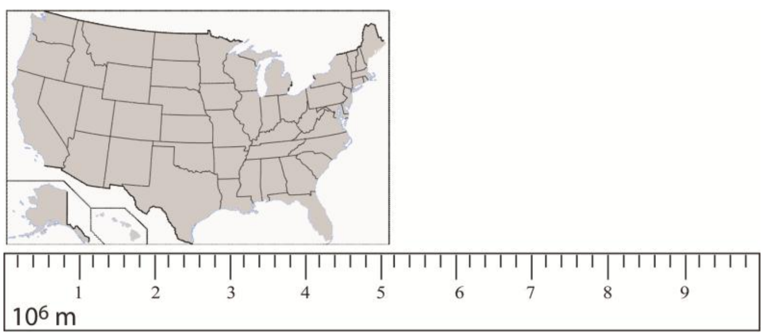
Virus



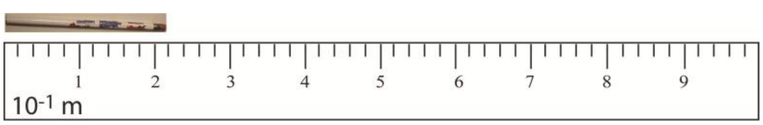
Hair width



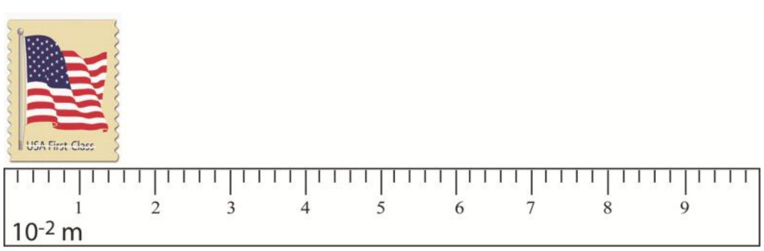
Cruising altitude of a 747



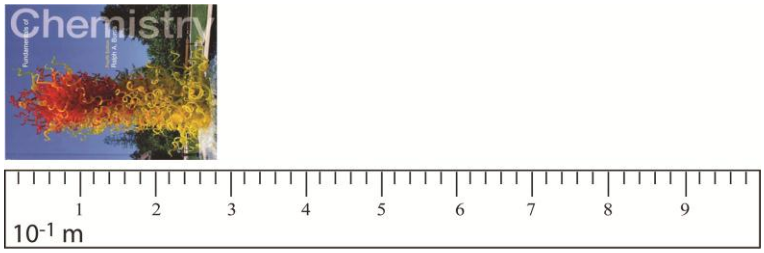
New York to LA



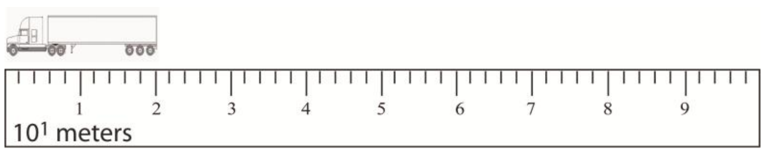
Pencil



Postage stamp

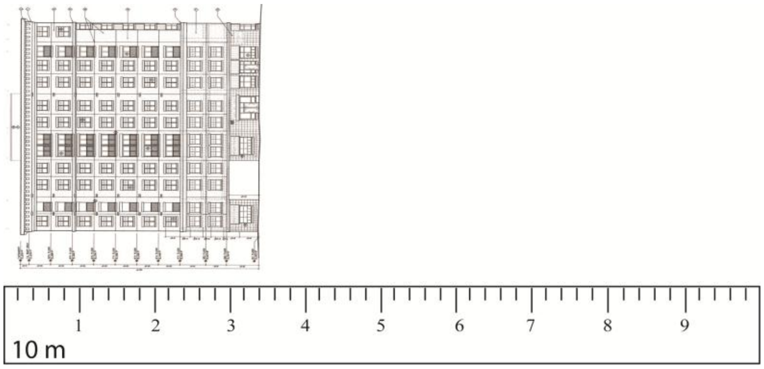


Textbook

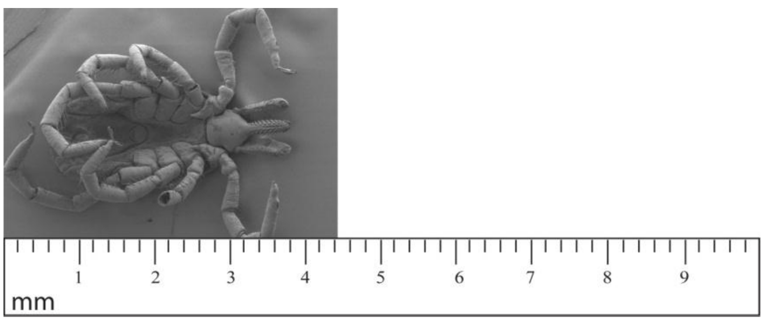


Semi truck

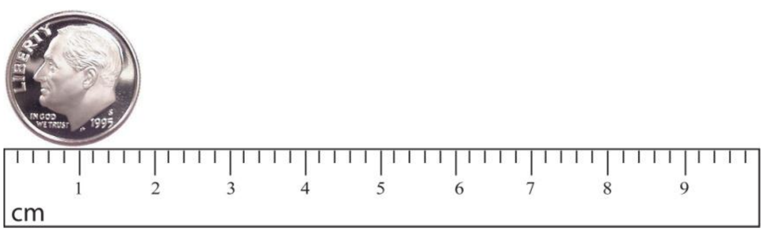
Unitizing/Anchoring Cards – Phase 2



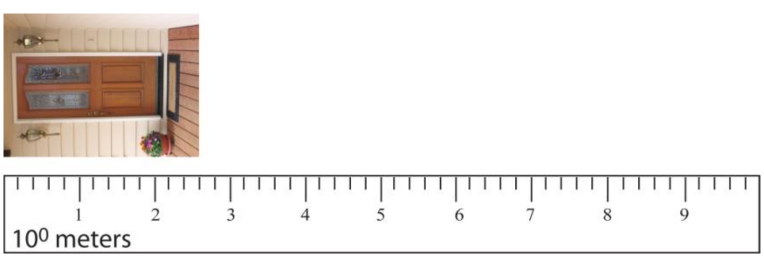
10 story building



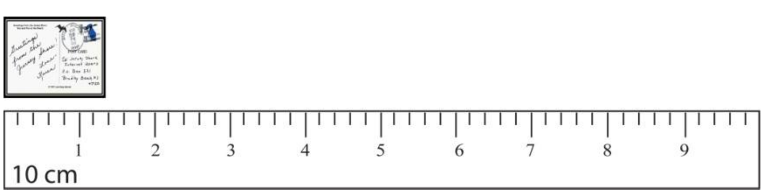
tick



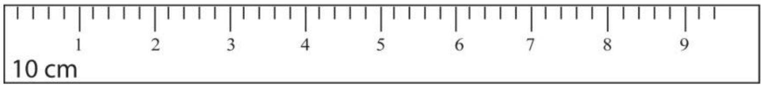
Dime



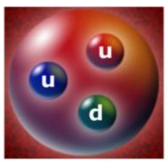
Doorway

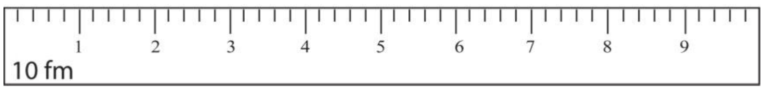


postcard

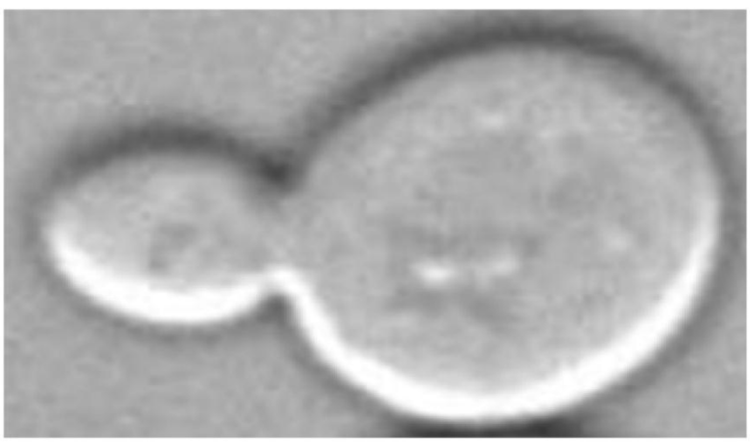


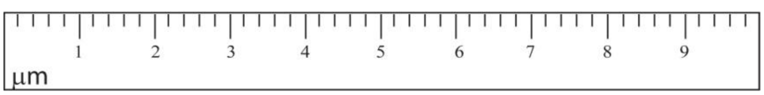
Football



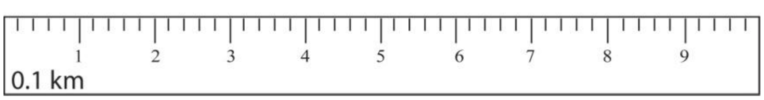


Proton

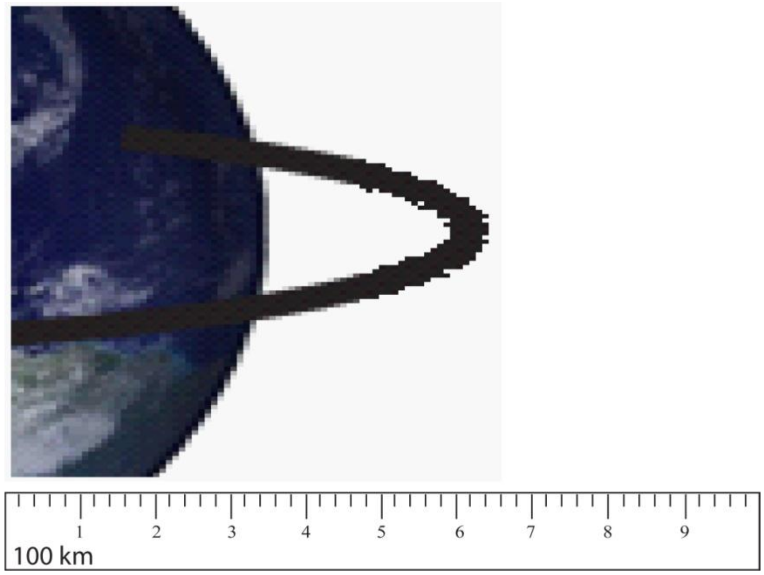




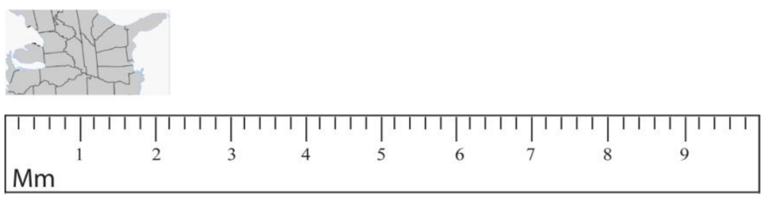
yeast cell



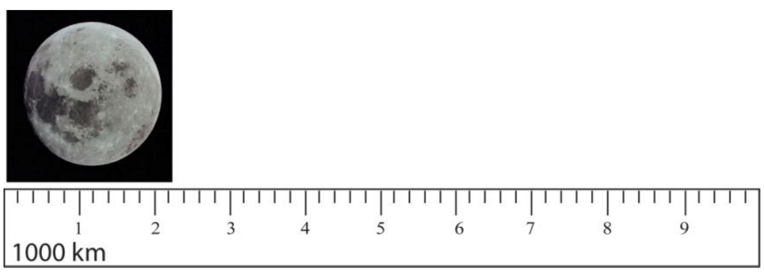
Miller park



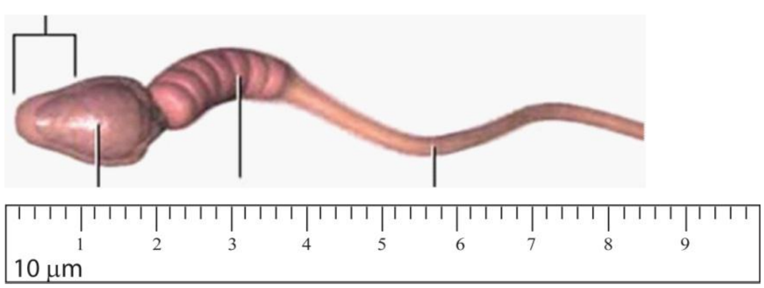
Altitude of international space station



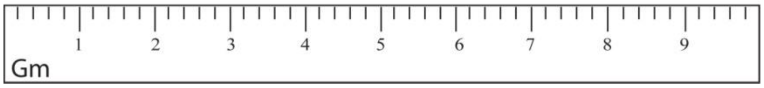
Milwaukee to Orlando



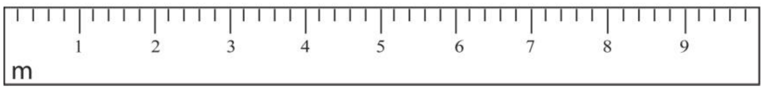
diameter of the moon



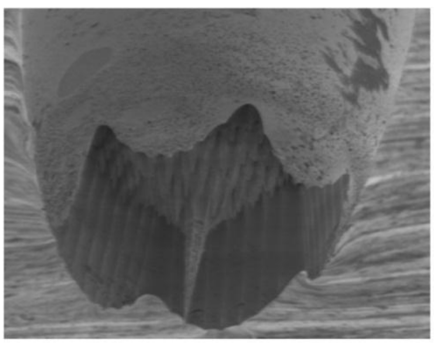
Sperm

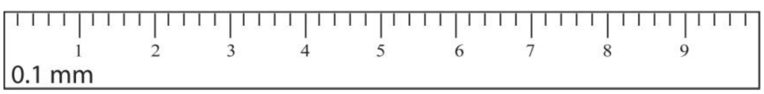


diameter of the sun

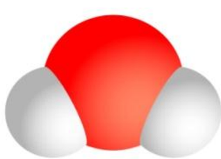


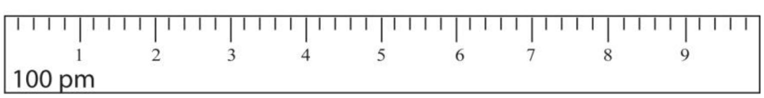
Telephone pole



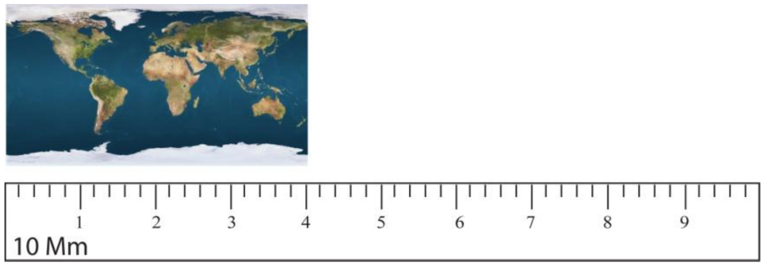


width of optical fiber



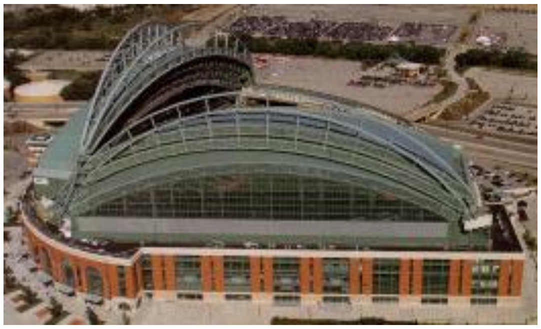


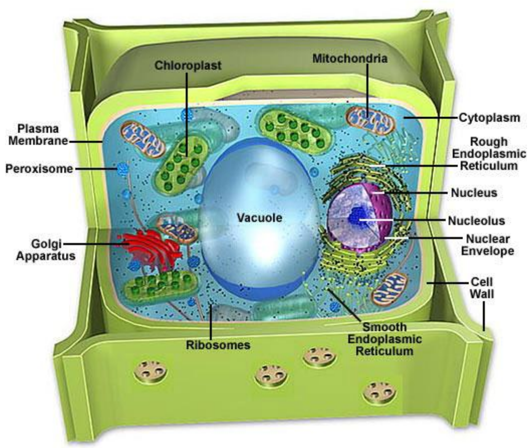
Water molecule

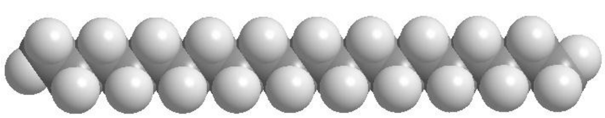


Circumference of the earth

Comparison Drawings – Phase 1

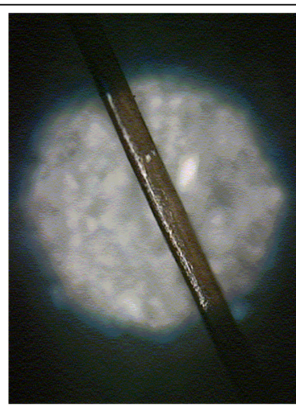
Baseball Stadium	**Baseball**
	

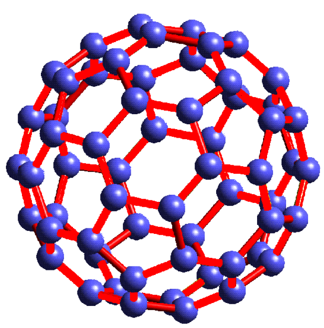
Plant Cell	**Water Molecule**
	

$C_{20}H_{42}$ Molecule	**Water Molecule**
	

Comparison Drawings – Phase 2

Earth Diameter	**_______________**
	

Hair Width	**Cell**
	

Buckyball	**Water Molecule**
	**Carbon atom**

APPENDIX B: ASSESSMENTS

- Scale Literacy Skills Test (SLST) – Fall 2009 to Fall 2011 Item Statistics
  - Preparatory Chemistry
  - General Chemistry I
- Scale Concept Inventory (SCI) – Fall 2009 to Fall 2011 Item Statistics
  - Preparatory Chemistry
  - General Chemistry I
- Correlation of assessments as predictors

SLST - Preparatory Chemistry

Based on the scores of 591 students
Fall 2009 to Fall 2011

Question Number	ATTR A	ATTR B	ATTR C	ATTR D		%A	%B	%C	%D	Diff.	Disc.
1	-0.08	-0.12	0.25	-0.05		5.92	7.61	82.57	3.05	0.83	0.25
2	0.09	0.27	-0.35	-0.02		19.12	49.24	22.00	9.31	0.49	0.27
3	0.22	-0.08	-0.04	-0.11		23.52	57.87	6.60	11.51	0.24	0.22
4	0.35	-0.15	-0.11	-0.12		20.64	66.16	6.60	6.43	0.21	0.35
5	0.15	0.12	-0.03	-0.26		6.60	7.11	3.05	83.08	0.07	0.15
6	0.44	-0.22	-0.06	-0.17		31.64	48.90	4.91	14.04	0.32	0.44
7	-0.06	-0.09	-0.23	0.37		2.54	18.27	47.04	32.15	0.32	0.37
8	-0.17	-0.25	-0.02	0.43		46.02	17.09	3.55	33.16	0.33	0.43
9	-0.10	-0.21	-0.02	0.33		6.77	39.42	1.86	51.61	0.52	0.33
10	-0.37	-0.06	0.48	-0.06		53.13	3.38	33.33	10.15	0.33	0.48
11	0.31	-0.06	-0.16	-0.10		58.38	4.57	29.44	7.61	0.58	0.31
12	0.00	0.47	-0.35	-0.13		0.51	51.78	30.46	17.26	0.52	0.47
13	-0.14	0.38	-0.06	-0.19		13.03	71.07	5.58	10.32	0.71	0.38
14	-0.02	0.39	-0.04	-0.33		25.89	32.49	9.98	31.13	0.32	0.39
15	-0.19	-0.08	-0.07	0.33		25.55	7.61	22.84	43.82	0.44	0.33
16	-0.13	-0.14	0.19	0.07		12.52	24.03	34.01	28.60	0.34	0.19
17	-0.18	0.16	0.03	-0.02		33.84	20.64	39.09	5.92	0.21	0.16
18	-0.04	0.12	0.08	-0.17		9.48	21.66	23.35	45.35	0.22	0.12
19	0.24	-0.01	-0.14	-0.11		27.58	21.83	35.36	14.55	0.28	0.24
20	0.01	0.19	-0.18	-0.04		23.69	33.84	37.90	4.57	0.34	0.19
21	-0.08	-0.08	-0.15	0.28		16.41	14.55	24.20	44.67	0.45	0.28
22	-0.19	-0.02	0.32	-0.12		26.40	20.30	40.27	13.03	0.40	0.32
23	-0.10	0.23	0.03	-0.17		33.84	27.24	17.94	20.81	0.27	0.23
24	0.08	-0.01	-0.06	-0.02		85.79	2.71	4.23	7.28	0.86	0.08
25	0.00	0.00	-0.04	0.02		16.07	61.76	16.07	5.92	0.16	-0.04
26	-0.02	0.02	-0.02	0.00		11.17	3.89	61.08	23.69	0.04	0.02
27	-0.02	-0.13	-0.12	0.26		2.88	16.24	19.97	60.91	0.61	0.26
28	-0.29	-0.03	0.36	-0.05		39.59	3.05	53.81	3.05	0.54	0.36
29	-0.15	0.06	0.13	-0.06		11.00	39.76	43.15	6.09	0.40	0.06
30	-0.09	-0.27	0.22	0.12		9.48	34.86	28.93	25.89	0.29	0.22
31	-0.08	0.24	-0.15	-0.04		6.43	71.07	17.26	4.57	0.71	0.24
32	0.15	-0.12	-0.05	0.01		47.04	46.70	4.57	1.69	0.47	0.15
33	-0.02	-0.20	0.29	-0.06		3.05	29.95	42.64	24.20	0.43	0.29
34	-0.13	0.03	0.02	0.08		13.37	21.15	25.55	39.76	0.26	0.02
35	0.02	0.13	-0.05	-0.12		15.06	27.07	25.89	31.98	0.15	0.02
36	-0.08	-0.29	0.34	0.01		6.94	39.59	42.81	10.32	0.43	0.34
37	-0.07	-0.14	0.27	-0.07		4.06	6.09	85.45	4.40	0.85	0.27
38	-0.02	0.18	-0.08	-0.10		1.86	86.13	4.74	7.28	0.86	0.18
39	0.33	-0.07	-0.18	-0.10		61.25	12.86	15.06	10.49	0.61	0.33
40	-0.12	0.40	-0.12	-0.18		7.45	53.98	23.69	14.55	0.54	0.40
41	-0.01	0.22	-0.04	-0.19		0.85	78.00	2.54	18.61	0.78	0.22
42	0.23	-0.08	-0.06	-0.11		49.41	13.20	23.52	13.54	0.49	0.23
43	0.18	0.01	-0.10	-0.12		32.83	43.49	13.87	9.31	0.33	0.18
44	0.19	-0.09	-0.06	-0.06		72.42	7.45	14.21	5.58	0.72	0.19
45	0.03	-0.08	-0.02	0.07		16.41	23.18	26.90	31.81	0.16	0.03

SLST - General Chemistry I

Based on the scores of 994 students
Fall 2009 to Fall 2011

Question Number	ATTR A	ATTR B	ATTR C	ATTR D	%A	%B	%C	%D	Diff.	Disc.
1	0.07	0.07	-0.19	0.04	3.52	5.04	89.53	1.41	0.90	0.18
2	0.11	-0.38	0.19	0.06	34.24	48.24	9.67	7.75	0.48	0.38
3	-0.44	0.28	0.08	0.07	58.91	29.31	5.74	5.94	0.59	0.43
4	-0.39	0.23	0.08	0.06	30.01	60.42	5.34	4.23	0.30	0.38
5	-0.32	-0.05	0.00	0.37	16.21	10.78	4.23	68.58	0.16	0.31
6	-0.50	0.28	0.05	0.16	44.11	40.79	4.93	9.87	0.44	0.49
7	0.01	0.16	0.36	-0.55	0.60	14.90	33.53	50.96	0.51	0.56
8	0.37	0.16	0.03	-0.58	40.79	11.48	1.71	45.82	0.46	0.56
9	0.05	0.23	0.02	-0.31	4.13	31.02	1.01	63.85	0.64	0.29
10	0.49	0.05	-0.58	0.03	43.50	2.92	42.90	10.37	0.43	0.57
11	-0.38	0.04	0.28	0.04	70.39	1.91	24.27	3.12	0.70	0.38
12	0.04	-0.56	0.29	0.20	1.61	67.17	17.42	13.49	0.67	0.57
13	0.09	-0.31	0.07	0.14	9.16	79.36	4.63	6.85	0.79	0.30
14	0.02	-0.33	0.05	0.25	42.80	36.05	3.83	17.12	0.36	0.33
15	0.19	0.06	0.10	-0.36	14.80	3.73	19.44	61.43	0.61	0.33
16	0.12	0.21	-0.36	0.01	8.56	19.23	44.81	27.19	0.45	0.38
17	0.16	-0.29	0.15	-0.03	21.65	20.85	51.36	6.14	0.21	0.29
18	0.02	-0.40	0.22	0.14	8.96	35.15	31.32	24.47	0.35	0.41
19	-0.29	-0.01	0.22	0.07	39.27	19.13	26.59	14.30	0.39	0.27
20	0.20	-0.45	0.23	0.02	20.75	45.32	32.43	1.51	0.45	0.44
21	0.08	0.10	0.16	-0.35	16.72	12.69	18.63	51.86	0.52	0.34
22	0.19	0.14	-0.40	0.06	19.44	16.11	57.10	7.35	0.57	0.40
23	0.24	-0.48	0.11	0.11	34.24	47.63	12.69	5.34	0.48	0.42
24	-0.09	0.01	0.06	0.01	87.71	2.22	2.82	7.25	0.88	0.09
25	0.06	0.02	-0.08	-0.01	7.85	74.32	11.28	6.55	0.11	0.07
26	0.02	-0.11	0.03	0.05	6.75	7.96	61.83	23.46	0.08	0.10
27	-0.01	-0.02	0.10	-0.09	1.51	14.30	13.90	70.19	0.70	0.07
28	0.38	0.03	-0.46	0.04	32.73	2.11	63.54	1.61	0.64	0.47
29	0.13	-0.03	-0.15	0.05	9.77	31.82	54.18	4.23	0.32	0.03
30	0.15	0.28	-0.38	-0.06	6.45	23.97	33.84	35.75	0.34	0.38
31	0.06	-0.33	0.22	0.04	3.52	72.00	20.34	4.13	0.72	0.31
32	-0.16	0.11	0.02	0.02	50.25	45.92	2.01	1.81	0.50	0.12
33	0.03	0.20	-0.25	0.00	1.31	22.26	48.64	27.79	0.49	0.25
34	0.09	0.02	-0.07	-0.06	7.25	20.95	22.05	49.75	0.22	0.04
35	-0.07	-0.06	-0.03	0.15	21.25	31.02	23.46	24.17	0.21	0.07
36	0.07	0.27	-0.31	-0.05	3.93	26.38	51.56	18.03	0.52	0.30
37	0.04	0.07	-0.14	0.02	2.32	4.43	89.43	3.83	0.89	0.11
38	0.04	-0.16	0.07	0.04	1.91	90.33	2.72	4.93	0.90	0.16
39	-0.33	0.11	0.12	0.08	74.42	12.59	7.96	4.93	0.74	0.32
40	0.05	-0.34	0.15	0.13	3.32	73.51	16.31	6.85	0.74	0.32
41	0.01	-0.21	0.03	0.17	0.81	86.30	1.71	11.18	0.86	0.18
42	-0.34	0.15	0.07	0.12	62.54	10.57	17.72	9.16	0.63	0.30
43	-0.28	0.17	0.07	0.03	42.30	52.17	3.93	1.51	0.42	0.25
44	-0.23	0.05	0.12	0.06	78.45	3.93	13.39	4.23	0.78	0.24
45	-0.08	0.11	-0.06	-0.01	30.11	12.08	30.51	26.08	0.30	0.05

Item Number	Answer	SCI - Preparatory Chemistry Based on the scores of 251 students Fall 2009 to Fall 2011					
		%A	%B	%C	%D	%E	%Omit
1	pos	39.8	21.5	2.4	19.5	16.7	0.0
2	neg	2.0	11.2	20.7	37.1	28.7	0.4
3	neg	33.1	26.3	6.8	19.5	14.3	0.0
4	pos	25.9	25.9	21.5	15.9	10.8	0.0
5	neg	4.0	13.1	11.2	35.1	36.7	0.0
6	pos	23.9	27.5	10.0	25.1	13.5	0.0
7	pos	13.9	20.3	34.3	16.3	14.7	0.4
8	pos	34.7	31.1	20.3	9.6	4.4	0.0
9	subj	11.6	23.9	24.3	27.5	12.7	0.0
10	pos	13.1	33.9	23.1	19.5	10.4	0.0
11	pos	15.1	25.1	29.9	22.7	7.2	0.0
12	pos	12.0	25.1	11.2	27.5	24.3	0.0
13	pos	24.7	32.3	27.5	10.8	4.8	0.0
14	neg	4.0	13.5	13.9	36.3	32.3	0.0
15	pos	31.5	36.7	10.8	14.3	6.4	0.4
16	pos	18.3	37.8	22.3	16.7	4.8	0.0
17	neg	33.9	36.3	12.7	9.2	8.0	0.0
18	subj	11.6	21.9	23.5	28.7	14.3	0.0
19	neg	14.3	19.1	26.7	25.1	14.7	0.0
20	pos	21.5	38.6	21.9	13.9	4.0	0.0
21	pos	13.5	28.7	23.9	28.3	5.6	0.0
22	pos	68.9	21.9	4.0	2.8	2.4	0.0
23	neg	7.6	14.7	27.1	31.5	19.1	0.0
24	subj	7.2	16.7	24.7	29.1	22.3	0.0
25	pos	19.9	32.3	19.9	18.3	9.6	0.0
26	pos	11.2	20.7	24.7	33.9	9.2	0.4
27	V	71.7	28.3	0.0	0.0	0.0	0.0
28	pos	27.1	26.7	23.9	19.1	3.2	0.0
29	pos	6.4	16.3	27.1	35.5	14.7	0.0
30	pos	3.6	12.4	32.3	29.1	22.7	0.0
31	neg	8.4	12.0	13.5	40.2	25.9	0.0
32	neg	15.5	45.8	24.3	8.8	5.6	0.0
33	pos	15.9	38.6	17.5	20.7	7.2	0.0
34	neg	21.9	32.3	28.3	12.4	4.8	0.4
35	neg	17.5	38.6	23.5	15.1	5.2	0.0
36	pos	22.7	43.0	22.7	9.2	2.4	0.0
37	neg	10.0	18.7	15.1	38.2	17.9	0.0
38	pos	5.6	18.3	24.3	37.5	14.3	0.0
39	pos	17.1	32.3	29.9	14.3	6.4	0.0
40	neg	28.3	37.5	15.5	11.6	6.8	0.4

Item Number	Answer	SCI - General Chemistry I Based on the scores of 618 students Fall 2009 to Fall 2011					
		%A	%B	%C	%D	%E	%Omit
1	pos	48.2	26.9	2.1	14.1	8.6	0.2
2	neg	1.6	6.6	19.6	38.3	33.5	0.3
3	neg	42.4	24.4	5.7	17.0	10.5	0.0
4	pos	22.5	32.0	14.6	18.6	12.0	0.3
5	neg	2.9	10.5	5.3	39.5	41.6	0.2
6	pos	36.7	33.8	8.6	16.5	4.4	0.0
7	pos	25.1	27.7	17.6	15.4	13.9	0.3
8	pos	50.0	23.5	16.8	5.8	3.9	0.0
9	subj	9.9	25.9	20.7	29.0	14.6	0.0
10	pos	19.4	33.3	19.7	19.7	7.6	0.2
11	pos	15.0	25.6	26.2	25.6	7.4	0.2
12	pos	11.3	21.8	7.4	33.0	26.2	0.2
13	pos	28.2	40.5	15.0	12.9	3.2	0.2
14	neg	3.4	8.3	16.5	33.3	38.3	0.2
15	pos	36.7	37.9	8.6	12.5	4.0	0.3
16	pos	27.7	37.2	18.0	14.2	2.8	0.2
17	neg	39.3	31.7	8.4	15.0	5.5	0.0
18	subj	7.6	19.9	25.2	31.9	15.2	0.2
19	neg	14.4	15.7	16.2	26.5	27.0	0.2
20	pos	27.5	40.3	16.2	13.1	2.9	0.0
21	pos	16.0	29.9	23.0	22.7	8.4	0.0
22	pos	70.4	19.9	3.4	4.0	2.1	0.2
23	neg	6.6	17.3	23.6	29.1	23.3	0.0
24	subj	9.5	18.1	19.7	29.3	23.3	0.0
25	pos	24.9	30.4	18.0	20.2	6.5	0.0
26	pos	14.4	20.9	26.9	30.1	7.4	0.3
27	V	71.2	28.8	0.0	0.0	0.0	0.0
28	pos	33.5	35.6	18.1	9.5	3.2	0.0
29	pos	9.9	15.9	23.5	37.7	13.1	0.0
30	pos	8.6	17.8	19.9	31.9	21.5	0.3
31	neg	6.0	12.0	9.7	41.1	31.2	0.0
32	neg	16.0	37.2	25.4	14.6	6.6	0.2
33	pos	11.7	30.9	16.8	29.6	10.8	0.2
34	neg	31.2	30.7	16.3	14.1	7.6	0.0
35	neg	12.8	32.4	25.2	20.4	9.1	0.2
36	pos	20.6	38.8	25.9	9.2	5.5	0.0
37	neg	6.3	14.6	13.3	43.0	22.8	0.0
38	pos	7.4	18.3	17.6	43.4	13.1	0.2
39	pos	23.6	35.8	20.2	15.2	4.9	0.3
40	neg	24.1	35.8	18.1	12.5	8.9	0.6

Correlations of Assessments

		ACT COMP	ACT READ	ACT ENGL	ACT MAT H	ACT SCIRE	Exam_ 1	Exam_ 2	Exam_ 3	Exam_ 4	Final P1 (40)	Final P2 (40)	%	TP Math	TP Chem	TP Total	Scale Pre	Scale Post	SLST	SCI Pre	SCI Post	SCI	Scale Literacy Pre	Scale Literacy Post
ACT COMP	Pearson Correlation	1	.839	.842	.773	.816	.397	.360	.327	.368	.529	.513	.237	.465	.427	.525	.477	.423	.096	.295	.318	.185	.486	.408
	N	966	965	966	966	964	957	933	914	889	898	898	966	914	914	913	853	288	262	634	412	354	584	319
ACT MATH	Pearson Correlation	.773	.453	.515	1	.638	.423	.364	.285	.345	.491	.483	.267	.524	.391	.524	.475	.412	.117	.234	.272	.146	.440	.399
	N	966	965	966	966	964	957	933	914	889	898	898	966	914	914	913	853	288	262	634	412	354	584	319
ACT SCIRE	Pearson Correlation	.816	.572	.553	.638	1	.324	.291	.228	.288	.419	.441	.172	.374	.366	.440	.424	.344	.071	.280	.269	.156	.435	.328
	N	964	963	964	964	964	955	931	912	887	896	896	964	912	912	911	851	288	262	633	412	354	583	319
TP Math	Pearson Correlation	.465	.282	.370	.524	.374	.437	.364	.283	.365	.439	.427	.279	1	.364	.709	.439	.439	.067	.198	.323	.203	.437	.430
	N	914	913	914	914	912	1056	1037	1005	981	992	991	1063	1063	1063	1062	962	334	309	722	477	416	672	373
TP Chem	Pearson Correlation	.427	.333	.322	.391	.366	.497	.400	.333	.386	.500	.504	.368	.364	1	.915	.501	.457	.007	.299	.341	.192	.506	.466
	N	914	913	914	914	912	1056	1037	1005	981	992	991	1063	1063	1063	1062	962	334	309	722	477	416	672	373
TP Total	Pearson Correlation	.525	.373	.404	.524	.440	.566	.460	.374	.451	.572	.568	.400	.709	.915	1	.573	.527	.033	.314	.396	.231	.578	.537
	N	913	912	913	913	911	1055	1036	1004	980	991	990	1062	1062	1062	1062	961	334	309	722	477	416	672	373
Scale Pre	Pearson Correlation	.477	.352	.334	.475	.424	.514	.386	.346	.437	.542	.586	.398	.439	.501	.573	1	.560	-.271	.397	.450	.156	.932	.567
	N	853	852	853	853	851	991	976	947	926	936	935	999	962	962	961	999	322	322	688	445	385	687	359
SCI Pre	Pearson Correlation	.295	.270	.189	.234	.280	.239	.196	.203	.226	.371	.441	.241	.198	.299	.314	.397	.378	-.066	1	.489	-.179	.702	.483
	N	634	633	634	634	633	741	736	725	712	725	722	745	722	722	722	688	261	244	745	405	403	687	293
Scale Lit Pre	Pearson Correlation	.486	.382	.345	.440	.435	.512	.389	.375	.441	.579	.640	.476	.437	.506	.578	.932	.607	-.210	.702	.536	.107	1	.646
	N	584	583	584	584	583	684	683	671	660	671	668	687	672	672	672	687	244	244	687	364	362	687	274

APPENDIX C: IN-CLASS MODULES

The in-class modules were designed to take one 50-minute period and the students were to answer via student response system (clickers). The modules consisted of a student handout that they would work through during the module as well as a series of questions that were entered into the student response or “clicker” system.

Initially, there was two modules (Scale and Unitizing/Anchoring) and they were aligned to be presented during specific content areas within the curriculum. These are considered version 1.

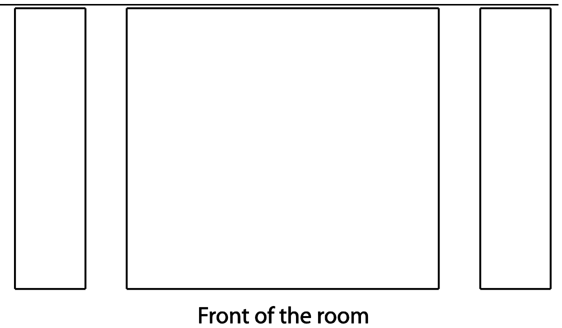
Versions 2 and 3 was a combined version of them and compressed to fit into one 50-minute period.

Version 1 Student Handouts

Scale Exercise

Part I:

1. Place an "x" where you are sitting today in the lecture hall.

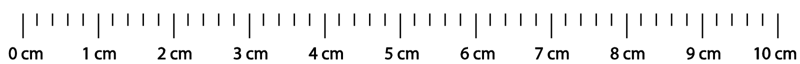


2. Select the item you will measure:

   ☐ Dime ☐ Ruler

3. Using your thumb and forefinger at thumb to nose length (see Dr. Murphy for how to do this), measure the item (dime or ruler). Using the ruler below, what is the length of your object?

   ______________ cm ______________ m



4. A standard dime is 1.8 cm wide and the ruler is 1 m long. What is the ratio of the size you measured versus the actual size of the object? _______________

5. What is the magnification (to the actual size) of the object? ____________________

Part II:

6. Human has an average width of 0.1 mm which is also the threshold for unaided sight of the human eye. **Using your clicker, answer: The sample of optical fiber has an outer diameter which is (A) greater than 0.1 mm or (B) less than 0.1 mm.**

7. Using the microscope, we will compare a sample of optical fiber and human hair. **Using your clicker, answer: Should the optical fiber outer diameter be visible to the unaided human eye? Answer (A) yes or (B) no.**

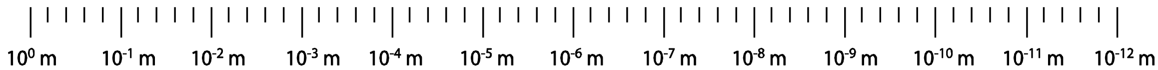
8. **Using your clicker, answer: Can you see it? (A) yes or (B) no.**

9. We will use a scanning electron microscope (SEM) to view images of an optical fiber tip at various magnifications. What is the magnification factor for:

   a. Going from 50x to 100x factor: ________________

   b. Going from 2000x to 5000x factor: ________________

10. Place the width of the optical fiber on the scale below (mark with an "×").



11. We will use a scanning electron microscope (SEM) to view images of a new object (a tick) at various magnifications. What is the magnification factor for:

    a. Going from 1200x to 12000x factor: ________________

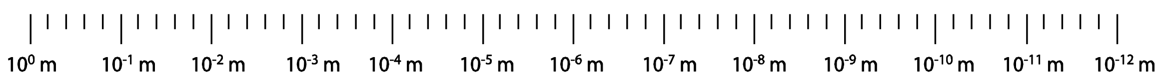
    b. Going from 12000x to 1200x factor: ________________

12. What is the magnification factor in terms of order of magnitude for:

    a. Going from 12000x to 1200x order of magnitude: ________________

    b. Going from 1200x to 120x order of magnitude: ________________

13. Place the width of the tick on the scale below (mark with an "×").



14. Would the tick be visible to the unaided human eye?

☐ yes ☐ no

Part III:

Janet Puppylove and her entire family have been suffering from intestinal issues. They were all put on medication which seemed to relieve the problem, however, shortly after they were all finished with the medication, the symptoms quickly returned. Everything in their house has been scrubbed down and there is still no change. You have suspicions that the household sponge may be the culprit and have narrowed the potential suspects to the only one of the three.

a. Influenza virus: spherical in shape, 100 nm (1×10^{-7} m) in size

b. Parasite (round worms): elongated 0.1 mm (1×10^{-4} m) long

c. *Escherichia coli* (*E. Coli*): elongated 2 µm (2×10^{-6} m) long

You have a sample of the sponge and have three instruments available to identify what the culprit

Hand lens	20x to 40x
Optical microscope	60x to 1600x
Scanning electron microscope (SEM)	2000x to 800 000x

15. If the desired size of the viewed image is 1 cm (1×10^{-2} m) to 4 cm (4×10^{-2} m), what is the magnification needed to view each "suspect"?
    a. Virus: ___________________
    b. Parasite: ___________________
    c. Bacterium: ___________________
16. Which instrument should be used to see each "suspect"?
    a. Virus: ______________________________________
    b. Parasite: ______________________________________
    c. Bacterium: ______________________________________
17. Using your clickers, you will get to vote on which instrument you would like to use and what magnification. Using this, you should look for the presence of the "suspect".
18. What is causing the family's intestinal issues?

Measurement and Scale Exercise

Name: ____________________________________

Chemistry 100, Lecture 401

DS Section: _____________________________

Part IV:

Scientists have been working on better ways to detect cancer in patients. The advent of nanoparticles has revolutionized many daily encounters and is also showing promise as detectors for cancer cells. Nanoparticles are chemically designed to bind with the RNA of cancerous cells, then when those cells encounter a laser light, they fluoresce so that doctors can cut out only the effected areas whilst allowing healthy tissue to remain. In this research, the nanotriangles are the desired nanoparticle for detecting cancer cells.

The particles have the sizes:

Nanotriangles:	100 nm
Nanorods:	1 μm
Nanowires:	10 μm

19. If the desired size of the viewed image is 1 cm (1×10^{-2} m) to 4 cm (4×10^{-2} m), what is the magnification needed to view each particle?
    a. Nanotriangles: ___________________
    b. Nanorods: ___________________
    c. Nanowires: ___________________

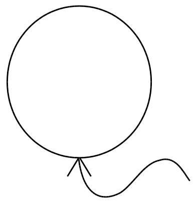
20. Using your clickers, you will get to vote on what magnification you would like image the nanoparticles. You will then examine the particles for shape and we will measure the particles to validate the identification.

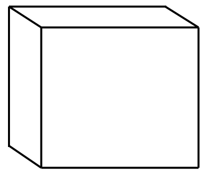
21. What type of nanoparticle is present in this sample?

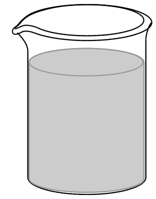
Unitizing/Anchoring Exercise

Part I:

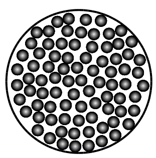
1. For the macroscopic representations, fill in solid, liquid, or gas.

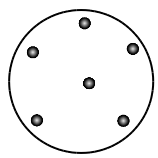

____

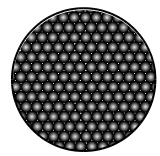

____


____

2. For the macroscopic representations, fill in solid, liquid, or gas.

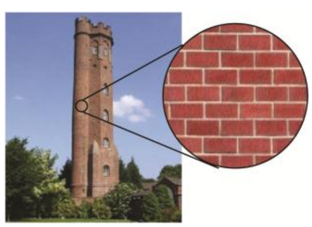

____


____


____

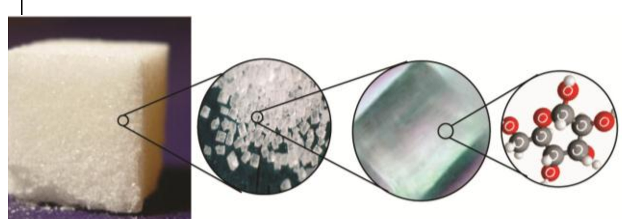
3. Using the images below, first define your particle, then use this to define the images as particle or macroscopic.

ticle__________________



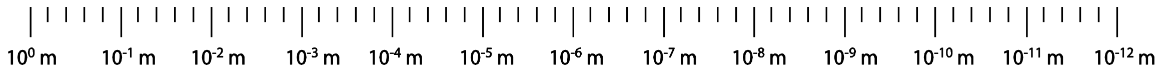
________ __________

ticle: __________________



________ __________ __________ __________

4. [Use the solids/liquids/gases representation as an example]
   On the scale, identify the macroscopic and particle regions (show the boundary between).



5. How do you identify the difference between a particle and a macroscopic representation?

Part II

One property that we will discuss on the macroscopic and particle level is lubrication.

6. What makes a good lubricant on the macroscopic scale?

7. **<u>Using your clicker</u>**, select the properties which would make a good lubricant.

8. **<u>Using your clicker</u>**, choose the picture that is the best lubricant.

9. What about the particle makeup would make a good lubricant?

10. **<u>Using your clicker</u>**, choose the picture that is the best lubricant.

Part III

The "lead" of your pencil is made of graphite.

11. Begin coloring in the box to the right. Describe the feel of the pencil as it starts to color in the box.

12. Finish coloring in the box. Does the feel of the pencil change? How?

13. Wipe your hands off and rub your finger on a blank section of paper. Now rub your finger over the darkened box. How is it different?

14. Is graphite a good lubricant? _____________ Why did you conclude that?

15. Graphite is carbon. Describe the macroscopic properties of graphite.

16. Predict one particle-level property of graphite.

Part IV

We have 3 instruments that we can use to view our sample of graphite:

Instrument	**Resolution**

Light microscope	.05 mm
Scanning electron microscope (SEM)	1 nm
Scanning tunneling microscope	50 pm

17. **<u>With your clicker</u>**, choose the instrument that will allow us to **<u>begin</u>** to see the lubrication property (hint: this is on the macroscopic scale).

18. Sketch what you observed

19. **<u>Using your clicker</u>**, did you see evidence from the image for why graphite is a good lubricant?

20. Knowing that the particle makeup of a substance gives it its macroscopic properties, what instrument will allow us to see the particle makeup of graphite? (**<u>Use your clicker to answer</u>**)

21. Sketch what you observed

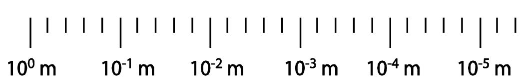
22. **<u>Using your clicker</u>**, did you see particles?

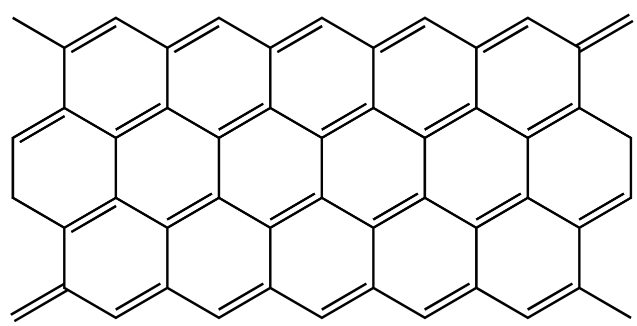
23. **<u>Using your clicker</u>**, what are these particles?

24. **<u>Using your clicker</u>**, which is the best particle representation of graphite

25. Now, complete the structure with carbon atoms (use C for the atom).

26. Using the following scale, place dots locating the correct position of macroscopic and particle graphite.





27. A single layer of graphite is called graphene and it has a thickness of 0.142 nm (1.42×10^{-10} m). The model of graphene has a thickness of 0.05 m. If the model is the actual size of graphene, how tall (in miles 1600 m = 1 mile) does that make Adam if he is 1.79 m?

Version 2 Student Handouts

Measurement and Scale Exercise

Part I:

Changing the size of an object is called magnification. The magnification value is how many times one can fit across another. Below is an example:

I can fit two dimes across, so the larger dime must have been multiplied by two, or magnified x2.

Hmmm…same number? Does that seem reasonable?

Mathematically, we look at how many times the original size can go into the new size.

$$\frac{\text{new size}}{\text{actual size}} = \text{magnification} \qquad \frac{1.4\text{ inch}}{0.71\text{ inch}} = 2$$

Do units matter? (Of course, notice what happens when you have the same top and bottom, they cancel…magnification is a unit less value)

1. How many dimes (0.71 inches) would fit across a dime that is 7.1 inches?
   How is this shown mathematically?

$$\frac{\text{new size}}{\text{actual size}} = \frac{7.1\text{ inches}}{} =$$

2. If a dime is magnified 100x, how wide (in inches) is the dime?

$$\frac{\text{new size}}{\text{actual size}} = \text{magnification} \qquad \left[\textit{solve for new size}\right]$$

The actual size of the dime is **0.71 inches**. Magnification makes something appear bigger:

- The dime magnified by 2 or 2x *(doubled)* is **1.4 inches**
- The dime magnified by 10 or 10x is **7.1 inches**

All of these magnifications make something smaller appear bigger.

Part II:

3. Human hair has an average width of 0.1 mm which is also the threshold for unaided sight of the human eye.

Using your clicker, answer: The sample of optical fiber has an outer diameter which is greater than 0.1 mm or less than 0.1 mm?

4. Using the microscope, we will compare a sample of optical fiber and human hair. **Using your clicker, answer:** Should the optical fiber outer diameter be visible to the unaided human eye?

5. **Using your clicker, answer:** Can you see it?

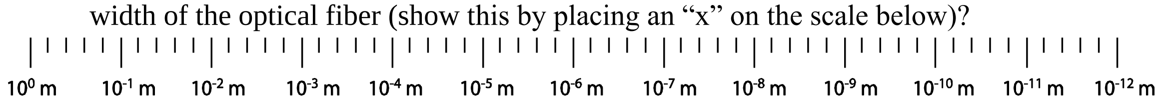
> You can also move from one magnification to another, the process is the same as above
> $$\frac{new\ magnification}{original\ magnification} = magnification\ change\ factor$$

6. We will use a scanning electron microscope (SEM) to view images of an optical fiber tip at various magnifications. What is the magnification factor for:

   a. Going from 50x to 100x   factor: ________________

   b. Going from 2000x to 5000x   factor: ________________

7. If the width of the fiber appears to be 6 cm at a magnification of 500x, what is the actual width of the optical fiber (show this by placing an "x" on the scale below)?



8. We will use the SEM to view images of a new object (a tick) at various magnifications. What is the magnification factor for:

   a. Going from 120x to 1200x   factor: ________________

   b. Going from 1200x to 12 000x   factor: ________________

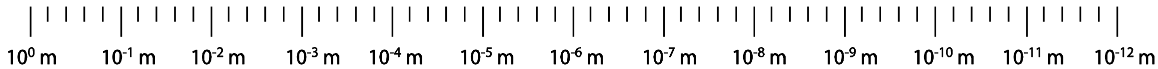
> When we have a factor of 10^{x}, it is referred to as an order of magnitude.
>
> $1000 = 1 \times 10^{3} = 10^{3}$ x = 3   3 orders of magnitude

9. What is the magnification factor in terms of order of magnitude for:

   a. Going from 1200x to 12 000x   order of magnitude: ________________

   b. Going from 120x to 1200x   order of magnitude: ________________

10. If the length of the tick appears to be 9 cm at a magnification of 30x, what is the actual length of the tick (show this by placing an "x" on the scale below)?



11. Would the tick be visible to the unaided human eye?

☐ yes ☐ no

Magnifications and orders of magnitude help us relate small or large objects back to a visible or usable size. For example, a virus is 7 orders of magnitude smaller than a human. If a virus was the size of a human, it would have to magnified 10^7 times or 10 000 000 (10 million times) times. That also means that 10 million viruses lined up end to end would be the height of 1 m.

12. **<u>Using your clicker, answer</u>**: If a human could shrink down to be the size of a virus (yech!), how many orders of magnitude would a human have to be reduced in magnification?

13. **<u>Using your clicker, answer</u>**: If an atom is 10^{-10} m, how many atoms would line up to equal the height of a human (10^0 m)?

You will now have a chance to use magnifications to work through a short problem. Based on the brief descriptions below, select the scenario you would like to solve:

Scenario 1: You will search for bacteria using the optical microscopes or the SEM.

Scenario 2: You will search for nanomaterials using the SEM.

Decide which scenario you would like to do. **<u>Using your clicker</u>**, vote for the scenario.

You will need to be able to calculate a magnification needed to view an object. Suppose you would like to image an influenza virus which is spherical in shape and 100 nm in size. You need to use a magnification so this appears to be 4 cm in size. What magnification do you use?

Remember that magnification is dimension-less. *You will need the two sizes in the same unit*.

Also, the new size is the product of the magnification and the actual size:

Actual size × magnification = new size

So magnification is equal to the new size divided by the actual size or:

$$\frac{\text{new size}}{\text{actual size}} = \text{magnification}$$

So to view the virus, The actual size is 100 nm = 100×10^{-9} m = $10^2 \times 10^{-9}$ m = 10^{-7} m

The new size is 4 cm = 4×10^{-2} m

So the magnification is:	$\frac{\text{new size}}{\text{actual size}} = \frac{4\times10^{-2}\ \text{m}}{10^{-7}\ \text{m}} = 400\,000\ \ (\text{magnification})$

Part III:

Janet Puppylove and her entire family have been suffering from intestinal issues. They were all put on medication which seemed to relieve the problem, however, shortly after they were all finished with the medication, the symptoms quickly returned. Everything in their house has been scrubbed down and there is still no change. You have suspicions that the household sponge may be the culprit and need to determine if the sponge contains the bacteria causing the problem. *Escherichia coli* (*E. Coli*) is elongated and approximately 1 μm long.

You have a sample of the sponge and have three instruments available to identify the bacterium:

Hand lens	20x to 40x
Optical microscope	60x to 1600x
Scanning electron microscope (SEM)	2000x to 800 000x

14. What are the sizes (in meters) of the bacterium?

15. The desired size of the viewed image is 1 cm to 4 cm. What are these sizes in meters?
    1 cm _________________ 4 cm _________________

16. **<u>Using your clicker, answer:</u>** Which image (1 cm or 4 cm) will require a larger magnification?

17. If the desired size of the viewed image is 1 cm to 4 cm, what is the magnification needed to view the bacterium?

18. Which instrument should be used to see the bacterium?

19. **<u>Using your clickers</u>**, you will get to vote on which instrument you would like to use and what magnification. Using this, you should look for the presence of the bacterium.

20. **<u>Using your clickers, answer:</u>** Is the family's illness caused by a bacterial infection?

Part IV:

Scientists have been working on better ways to detect cancer in patients. The advent of nanoparticles has revolutionized many daily encounters and is also showing promise as detectors for cancer cells. Nanoparticles are chemically designed to bind with the RNA of cancerous cells, then when those cells encounter a laser light, they fluoresce so that doctors can cut out only the effected areas whilst allowing healthy tissue to remain. In this research, the nanotriangles are the desired nanoparticle for detecting cancer cells.

The particles have the sizes:

Nanotriangles	100 nm
Nanorods	1 μm
Nanowires	10 μm

21. What are the sizes (in meters) of the nanotriangles?

22. The desired size of the viewed image is 1 cm to 4 cm. What are these sizes in meters?
    1 cm ________________ 4 cm ________________

23. **Using your clicker, answer:** Which image (1 cm or 4 cm) will require a larger magnification?

24. If the desired size of the viewed image is 1 cm to 4 cm, what is the magnification needed to view the nanotriangles?

25. **Using your clickers**, you will get to vote on what magnification you would like image the nanoparticles. You will then examine the particles for shape and we will measure the particles to validate the identification.

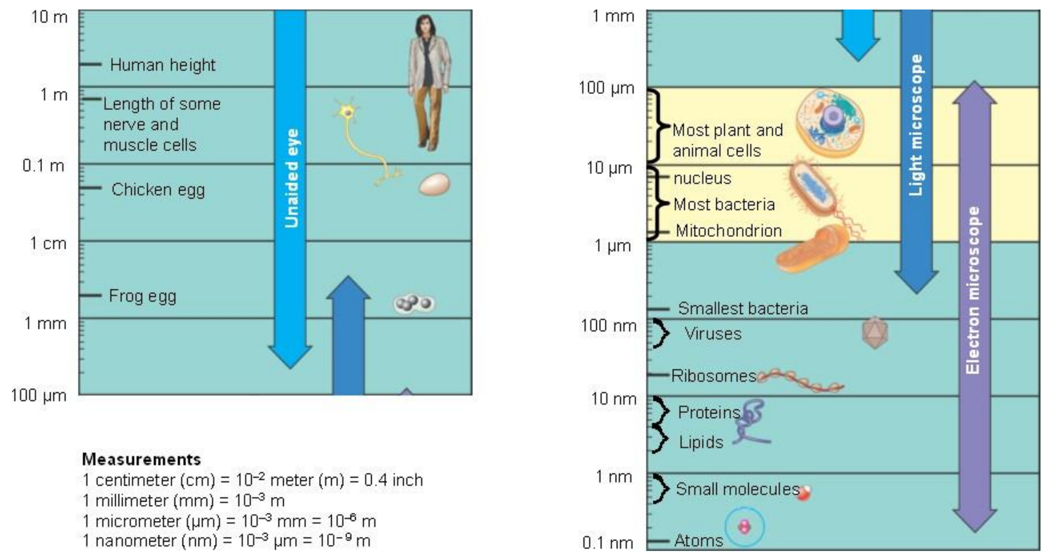
26. **Using your clickers,answer:** What type of nanoparticle is present in this sample?

Version 3 Student Handouts

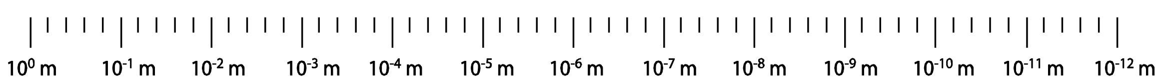
Scale and Particle vs Macroscopic

Part I: Why Scale?

We will start with a series of images across a large range of spatial scale (going smaller):



1. On the scale below, mark a “window” or “range” where chemistry is explained.



Part II: Number Sense

Because our area of interest is so much smaller – we use exponents to express the sizes. As a refresher, we will discuss using exponents.

To move about between units and sizes, we must be very comfortable using exponents in arithmetic operations.

To add two values, the exponents must be the same:

$$10^{-3} + 10^{-5} = 1\times10^{-3} + 1\times10^{-5} = 100\times10^{-5} + 1\times10^{-5} = 101\times10^{-5} \approx 100\times10^{-5} = 10^{-3}$$

To subtract two values, the exponents must also be the same:

$$10^{-2} - 10^{-4} = 1\times10^{-2} - 1\times10^{-4} = 100\times10^{-4} - 1\times10^{-4} = 99\times10^{-4} \approx 100\times10^{-4} = 10^{-2}$$

To multiply two values, the coefficient is multiplied and the exponents are added:

$10^{-2} \times 10^{-4} = 1{\times}10^{-2} \times 1{\times}10^{-4} = 1{\times}10^{(-2 + -4)} = 1{\times}10^{-6} = 10^{-6}$

To divide two values, the coefficients are divided and the exponents are subtracted:

$10^{-3} / 10^{-6} = 1{\times}10^{-3} / 1{\times}10^{-6} = 1{\times}10^{(-3 - -6)} = 1{\times}10^{(-3 + 6)} = 1{\times}10^{3} = 10^{3}$

Some practice with this combining with unit conversions:

2. 100 pm = 10^x m, what is x?

3. You have something that is 10 cm long and to this you add something that is 10 µm. How long is the sum of the two?

Part III: What is Magnification?

Changing the size of an object is called magnification. The magnification value is how many times one can fit across another. Below is an example:

Mathematically, we look at how many times the original size can go into the new size.

$$\frac{\text{new size}}{\text{actual size}} = \text{magnification} \qquad \frac{1.4\text{ inch}}{0.71\text{ inch}} = 2$$

Do units matter? (Of course, notice what happens when you have the same top and bottom, they cancel…magnification is a unitless value)

4. How many dimes (0.71 inches) would fit across a dime that is 7.1 inches? How is this shown mathematically?

$$\frac{\text{new size}}{\text{actual size}} = \frac{7.1\text{ inches}}{} =$$

5. If a dime is magnified 100x, how wide (in inches) is the dime?

$$\frac{\text{new size}}{\text{actual size}} = \text{magnification} \qquad [\textit{solve for new size}]$$

All of these magnifications make something **smaller appear bigger**. All of these magnifications are greater than one.

Part IV: How do we use magnification?

Human hair has an average width of 0.1 mm which is also the threshold for unaided sight of the human eye. Optical fibers typically have a diameter about 0.20 mm.

6. **<u>Using your clicker, answer:</u>** Using the microscope, we will compare a sample of optical fiber and human hair. Should the optical fiber outer diameter be visible to the unaided human eye?

You can also move from one magnification to another, the process is the same as above

$$\frac{new\ magnification}{original\ magnification} = magnification\ change\ factor$$

When we have a factor of 10^x, it is referred to as an order of magnitude.

$1000 = 1 \times 10^3 = 10^3$ x = 3 3 orders of magnitude

7. We will use a scanning electron microscope (SEM) to view images of an optical fiber tip at various magnifications. What is the magnification factor for:

   c. Going from 50x to 100x factor: ________________

   d. Going from 100x to 1000x factor: ________________

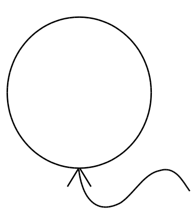
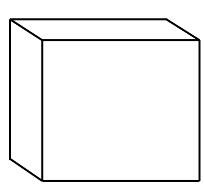
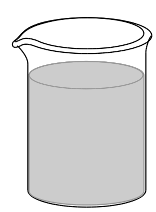
Magnifications and orders of magnitude help us relate small or large objects back to a visible or usable size. For example, a virus is 7 orders of magnitude smaller than a human. If a virus was the size of a human, it would have to magnified 10^7 times or 10 000 000 (10 million times) times. That also means that 10 million viruses lined up end to end would be the height of 1 m.

8. **<u>Using your clicker, answer:</u>** If an atom is 10^{-10} m, how many atoms would line up to equal the height of a human (10^0 m)?

Part V: Particle vs. Macroscopic

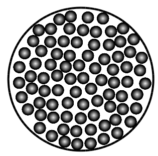
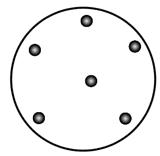
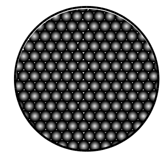
To be able to discuss properties, we have to clarify the difference between macroscopic and particle representations.

9. For the macroscopic representations, fill in solid, liquid, or gas.

__________ __________ __________

10. For the particle representations, fill in solid, liquid, or gas.

__________ __________ __________

11. What is the difference between a macroscopic and particle representation?

We <u>observe</u> on the macroscopic level. This is due to its <u>structure</u> on the particle level – we <u>explain</u> the macroscopic observations on the particle level.

Part VI: Using magnification to explore properties of matter

One property that we will discuss on the macroscopic and particle level is lubrication.

12. Describe what makes a good lubricant on the macroscopic scale.

13. **<u>Using your clicker, answer:</u>** Looking at the images provided, which picture(s) describe(s) a good lubricant?

14. What particle-level structure do you think would make a good lubricant?

15. **<u>Using your clicker, answer:</u>** Looking at the images provided, which picture(s) describe(s) a good lubricant on the particle level?

Part VII: Using Macroscopic observations to discuss Macroscopic properties

The "lead" of your pencil is made of graphite.

16. Color the box to the right. Describe the feel of the pencil as it starts to color in the box.
17. **<u>Using your clicker, answer:</u>** Is graphite a good lubricant?

    Why did you conclude that?

18. Graphite is carbon. Describe the macroscopic properties of graphite (how does it look, feel, etc).

19. Predict one particle-level property of graphite.

Part VIII: Using microscopic and particle observations to discuss macroscopic and particle properties

We have 3 instruments that we can use to view our sample of graphite:

Instrument	**Resolution**	
Light microscope	.05 mm	5×10^{-5} m
Scanning electron microscope (SEM)	1 nm	10^{-9} m
Scanning tunneling microscope	50 pm	5×10^{-11} m

The size of an atom is on the order of 100 pm or 10^{-10} m.

20. **Using your clicker, answer:** which instrument(s) would you like to use to provide images of graphite on the *macroscopic scale*?

    (How would you calculate this?)

21. Sketch what you observed:

22. **Using your clicker, answer:** From the image, did you see evidence from the image for why graphite is a good lubricant?

23. **Using your clicker, answer:** Which instrument(s) would you like to use to provide images of graphite on the particle-level?

    (How would you calculate this?)

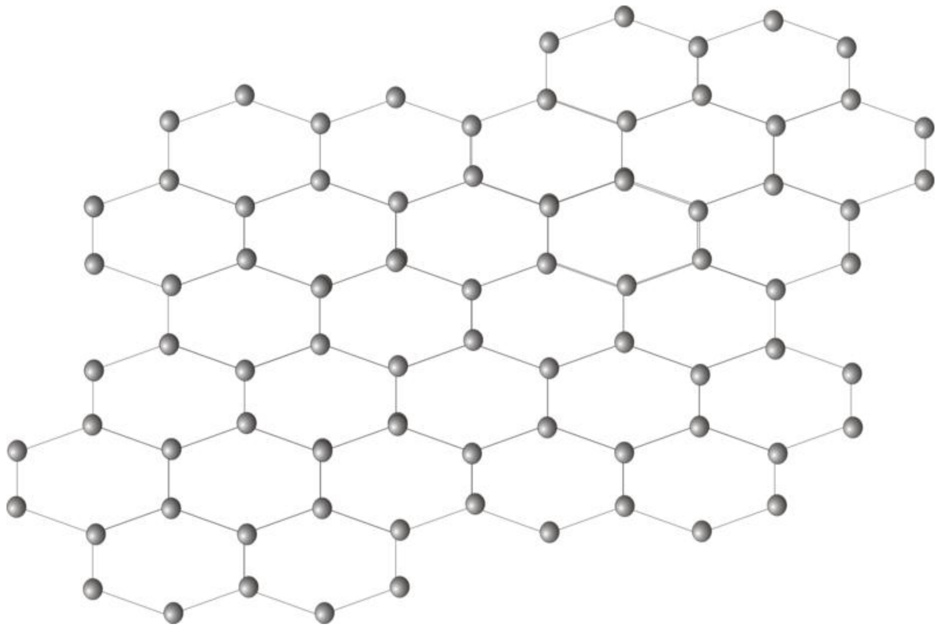
24. Sketch what you observed

25. **Using your clicker, answer:** From the image, did you see particles?

26. **Using your clicker, answer:** What are these particles?

27. **Using your clicker, answer:** From the images provided, which is the best particle representation of graphite?

28. Circle the some carbon atoms in the structure of graphite below.

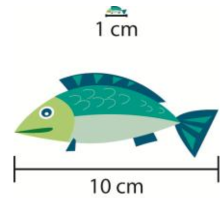


29. What would a water molecule look like on top of a layer of graphite? Draw this on the model above.

Scale Questions

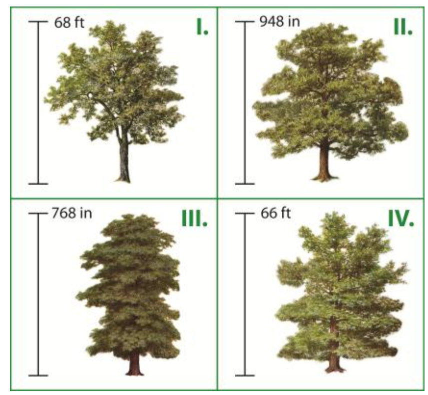
Scale – Pretest (pre-instruction)

1. The human eye can see unaided to 0.1 mm. Which object(s) is/are smaller than 0.1 mm?
   I. A bacterium
   II. The width of a human hair
   A. Only I B. Only II C. Both I and II
   D. Neither I nor II



2. By what value has the bottom figure been magnified with the respect to the top figure?

3. How many orders of magnitude smaller is nano- than micro-?



4. Which tree is the largest?

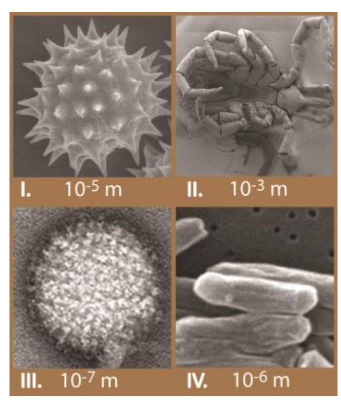
   A. I B. II C. III D. IV

5. The Greek prefix “micro-“ is abbreviated as □. What is the value of x in the equivalency of micrometers to meters? 1 □m = 1×10^x m

Scale – Pretest (pre-instrumentation)

1. The human eye can see unaided to 0.1 mm. Which objects are smaller than 0.01 mm?
   I. An atom
   II. A virus
   A. Only I B. Only II C. Both I and II
   D. Neither I nor II

2. The average king piece in chess is 2.5 inches tall. In the picture, the boy is standing next to a king that is 36 inches tall, by what value was the chess piece in the figure magnified?



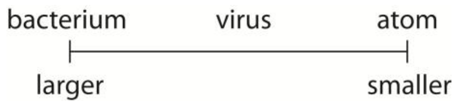
3. How many orders of magnitude larger is milli- than nano-?

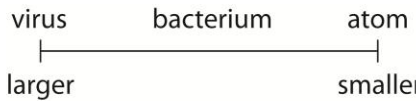
4. An ant is approximately 1 cm long. Which figure is 3 orders of magnitude smaller than an ant?
   A. I B. II C. III D. IV

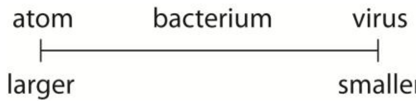
5. The Greek prefix “micro-“ is abbreviated as □. What is the value of x in the equivalency of micrometers to meters?
   1 m = 1×10^x□m

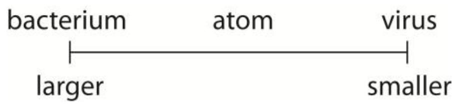
Scale – Posttest I

1. What is the order of size for a virus, bacterium and atom?

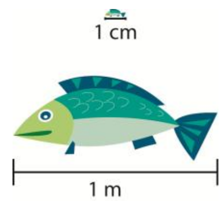
A. 

B. 

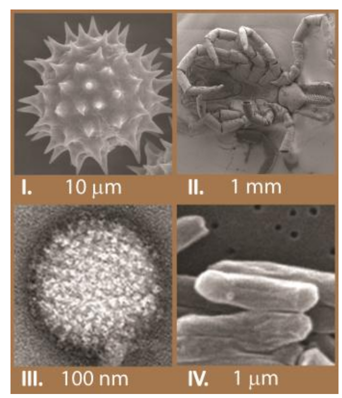
C. 

D. 

2. By how many orders of magnitude has the bottom figure been magnified with the respect to the top figure?



3. How many orders of magnitude smaller is pico- than milli- ?



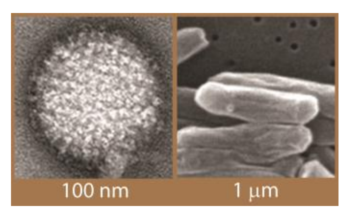
4. A dime is approximately 10^{-2} m long. Which figure is 4 orders of magnitude smaller than a dime?

   A. I   B. II   C. III   D. IV

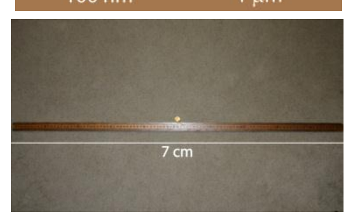
5. The Greek prefix nano- has the abbreviation of n. What is the value of y when: 1 nm = 1 x 10^{y} m?

Scale – Prottest II

1. Which is larger, a virus or bacterium, and by how many order(s) of magnitude?
   A. A bacterium is larger by 1 order of magnitude
   B. A bacterium is larger by 2 orders of magnitude
   C. A virus is larger by 1 order of magnitude
   D. A virus is larger by 2 orders of magnitude



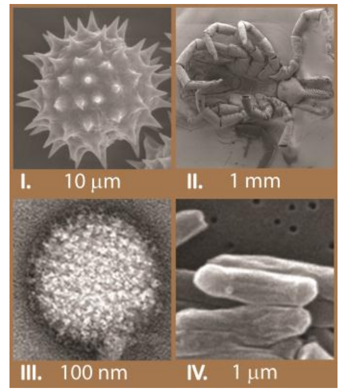
2. In the scale activity, a student measures the ruler as shown in the figure. What is the calculated magnification to actual size? (The ruler is 1 m.)



3. How many orders of magnitude smaller is pico- than micro-?

4. If the frame size on the images to the right are each 10 cm, which image has been magnified by 5 orders of magnitude?

5. The Greek prefix pico- is abbreviated as p. What is the value of x when 1 m = 1×10^x pm



Scale Activity

Part I

1. Question 4:
2. Question 5
3. Question 9
4. Question 12

Part II

5. Question 13
6. Question 14
7. Question 15
8. Question 22
9. Question 23

Part III

10. Question 27
11. Which will require the greatest magnification? A. bacterium B. parasite C. virus
12. Question 30: What instrument would you like to use first?
    A. Hand-lens B. Optical microscope C. SEM
13. Hand-lens: What are you trying to identify?
    A. bacterium B. parasite C. virus
14. Hand-lens: What magnification would you like to see?
    A.20x B. 40x
15. Optical microscope: What are you trying to identify?
    A. bacterium B. parasite C. virus
16. Optical microscope: What magnification would you like to see?
    A.100x B. 400x C. 1000x
17. SEM: What are you trying to identify?
    A. bacterium B. parasite C. virus
18. SEM: What magnification would you like to see?
    A.5000x B. 10 000x C. 15 000x
19. SEM: What magnification would you like to see?
    A.40 000x B. 80 000x C. 180 000x
20. Have you identified what is causing the family's illness?
21. What is responsible for the intestinal issues suffered by the Puppylove Family?
    A. bacterium B. parasite C. virus

Part IV

22. Which magnification should be used first?
    A. 4000x B. 10 000x C. 100 000x
23. Are there a high percentage of silver nanotriangles which will enter the cells in this sample?

A. yes B. no C. cannot be determined from this scan

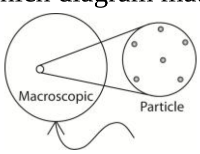
24. Which magnification should be used next?
    A. 4000x B. 10 000x C. 100 000x
25. Are there a high percentage of silver nanotriangles which will enter the cells in this sample?
    A. yes B. no C. cannot be determined from this scan
26. Which magnification should be used last?
    A. 4000x B. 10 000x C. 100 000x
27. Are there a high percentage of silver nanotriangles which will enter the cells in this sample?
    A. yes B. no C. cannot be determined from this scan
28. What type of nanoparticle is present in this sample?
    A. nanotriangles B. nanorods C. nanowires

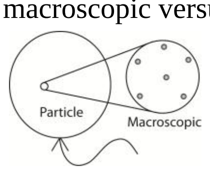
Unitizing/Anchoring Questions

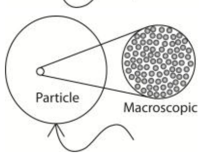
Unitizing/Anchoring – Pretest (pre-instruction)

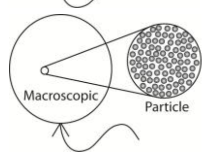
---

6. Which diagram matches a macroscopic versus a particle representation of a gas?

A. 

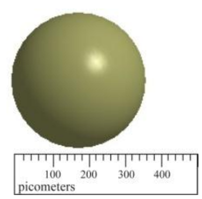
B. 

C. 

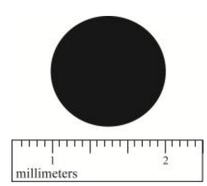
D. 

7. A new unit of length is defined as an auto hour (ah) which is the distance an automobile can travel in 1 hour. 1 ah = 60 miles.
   The circumference of Earth is 25 000 miles. What is this distance in auto hours (ah)?
   420 +/- 25

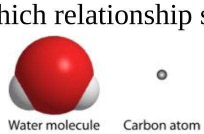
8. A unit of length which is on the order of atoms is called an angstrom, Å. 1 Å = 1×10^{-8}cm. A lead atom is shown on a picometer scale in the figure. What is the length of this atom in angstroms? 3.50 +/- 0.2

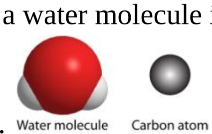


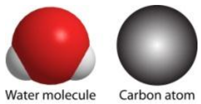
9. Approximately how many carbon atoms placed end to end would make a line that would cross the dot in the figure to the right?
   A. 10 B. 10^3
   C. 10^7 D. 10^{12}

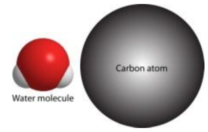


10. Which relationship shows a water molecule in relation to an carbon atom?

A. 

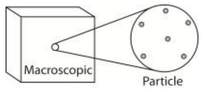
B. 

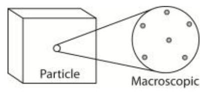
C. 

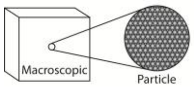
D. 

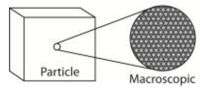
Unitizing – Pretest (pre-instrumentation)

6. Which diagram matches a macroscopic versus a particle representation of a solid?

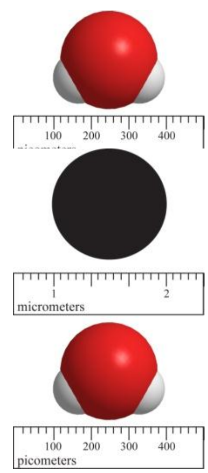
A. 

B. 

C. 

D. 

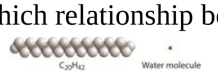
7. A unit of length for measuring the height of a horse is the hand (ha). 1 ha = 4 inches. An female human is 6.0 feet tall. What is this height in hands?
18 +/- 0

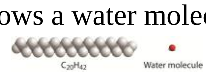


8. A unit of length which is on the order of atoms is called an angstrom, Å.
1 Å = 1x10^{-8} cm.
A water molecule is shown on a picometer scale in the figure. What is the length of this molecule in angstroms?
3.0 +/- 0.2

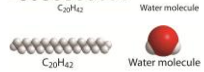
9. Approximately how many water molecules (shown in the figure) placed end to end would make a line that would cross the dot in the figure to the right? 3000 +/- 1000

10. Which relationship best shows a water molecule in relation to $C_{20}H_{42}$?

A. 

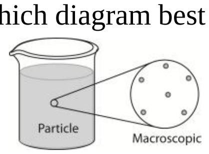
B. 

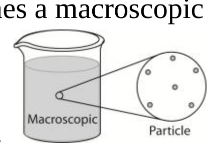
C. 

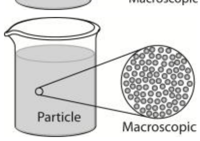
D. 

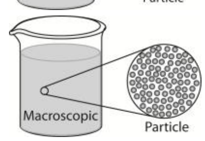
Unitizing – Posttest I

6. Which diagram best matches a macroscopic versus a particle representation of a liquid?

A. 

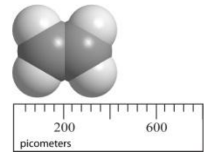
B. 

C. 

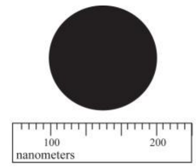
D. 

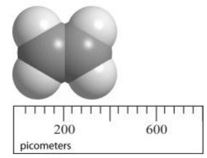
7. An antiquated unit measure called the munchkin was once used to measure volumes of liquids. 1 munchkin = $^{3}/_{4}$ pint How many munchkins are in 10 gallons of milk?
(2 pints = 1 quart; 4 quarts = 1 gallon)

107 +/- 2



8. 1 Å = 1x10^{-8} cm. An ethylene is shown on a picometer scale in the figure. What is the length of this molecule in angstroms?
420 +/- 0.5

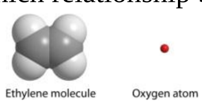


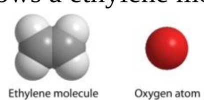


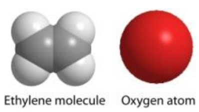
9. Approximately how many ethylene molecules placed end to end would make a line that would cross the dot in the figure to the right?

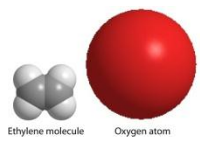
A. 1 B. 4.2
C. 240 D. 240 000

10. Which relationship best shows a ethylene molecule in relation to an oxygen atom?

A. 

B. 

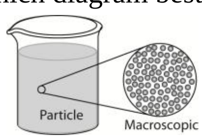
C. 

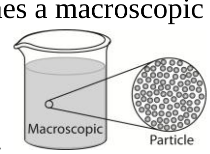
D. 

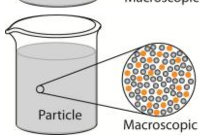
Unitizing – Posttest II

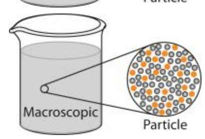
---

6. Which diagram best matches a macroscopic versus a particle representation of a solution?

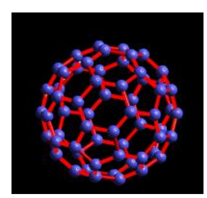
A. 

B. 

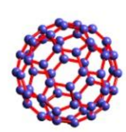
C. 

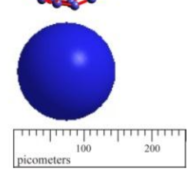
D. 

7. A chain is a unit to measure lengths. 1 chain = 22 yards
How many square chains are in 1 acre (43, 560 ft^2)? (1 yard = 3 feet)
10 +/- 0.5



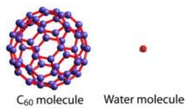
8. 1 Å = 1x10^{-8} cm. A buckyball (C_{60}) is shown in the figure. The diameter of this molecule is approximately 1 nm. What is the diameter of this molecule in angstroms?
10 +/- 0.5

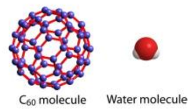


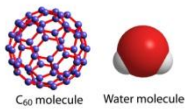


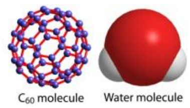
9. Approximately how many carbon atoms placed end to end would make a line that would cross the buckyball (outer diameter = 10 A) in the figure to the right?
   7 +/- 1

10. Which relationship best shows a water molecule in relation to C_{60}?

A. 

B. 

C. 

D. 

Unitizing Activity

---

7. On the macroscopic scale, which properties would make a good lubricant?

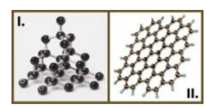
I.	rough	II.	slippery
III.	smooth	IV.	sticky

A. I and II B. I and IV C. II and III D. III and IV

8. Which macroscopic picture(s) are good lubricants?

A. I only B. III only C. I and III
D. II and IV E. III and IV

10. Which particle-level picture(s) are good lubricants?



A. I only B. II only
C. Both I and II D. Neither I nor II

17. Which instrument should we use to **<u>begin</u>** to see the lubrication property of graphite?
    A. light microscope B. SEM C. scanning tunneling microscope

19. Did you see evidence from the image for why graphite is a good lubricant?
    A. yes B. no

20. Which instrument should we use to see the particle makeup of graphite?
    A. light microscope B. SEM C. scanning tunneling microscope

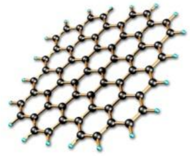
22. Did you see particles?
    A. yes B. no

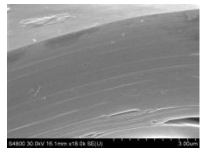
23. What are these particles?
    A. atoms B. electrons C. molecules
    D. atomic nuclei E. nanoparticles

24. Which is the best particle representation of graphite?

A. 

B. 

C. 

D. 

APPENDIX D: SUPPLEMENTAL INSTRUCTION

The supplemental instruction was designed to be used on a classroom management software but could be designed to be used on other software packages where conditions would need to be met to move on.

The outline for both the Scale and Unitizing/Anchoring activities is provided as well as the hints for both activities. Handouts were provided for the students and they are included following the hints.

Scale Activity

Initial Activity Questions:

1. Number sense
2. Converting
3. Conceptualizing relative sizes
4. Visual spatial skills
5. Visualizing scales
6. Visualizing scales
7. Applying conceptual anchors
8. Relating one scale to another

Scoring: 7-8 (>=75%) – high 5-6 (50-75%) – medium 0-4 (<50%) – low

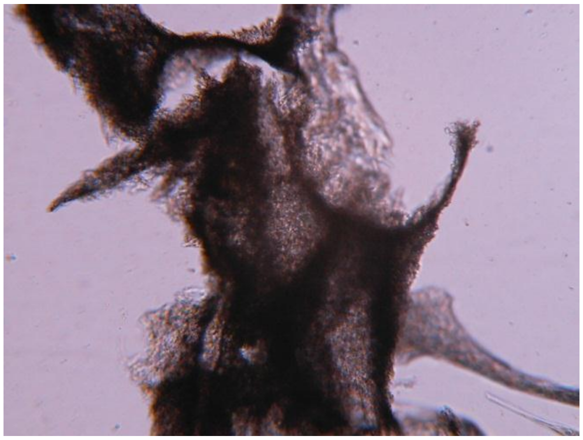
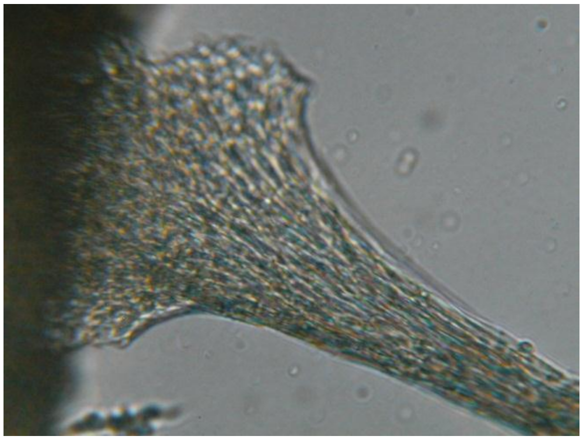
---

Scenario 1: Introduction

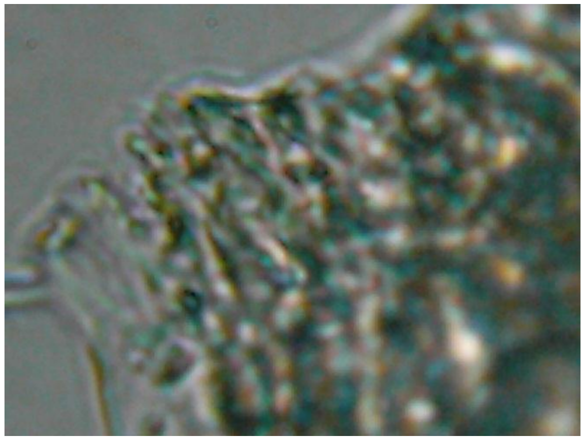
Although you may have done something very similar in lecture, in this activity, you are going to examine a kitchen sponge for one of two things that could be making a family sick. After eliminating other possibilities, it was determined that the Wilson family was sick due to an intestinal parasite, the round worm, or a bacterium, *Escherichia coli* (*E. Coli*). You have a sample of the sponge and can collect images using a hand scope/optical microscope or a scanning electron microscope. Please use the hints provided as they are designed to help you with answering the questions. Good luck!

1. First, you are going to look for a parasite in the sponge. You are looking for a round worm that is elongated and approximately 0.1 mm long. What is this size in meters? [There is a hint for converting units]
   A. 10^{-2} m
   B. 10^{-3} m
   C. 10^{-4} m

2. What instrument would you like to use to image the sponge to look for the round worm? The resolution of the instruments is given. [There is a hint to describe the instruments.]
   A. Hand scope or optical microscope (insert resolution from activity)
   B. Scanning electron microscope

3. What magnification would you like to see? [There is a hint to describe how to determine a magnification.]
   A. 20x
   
   B. 40x
   
   C. 100x
   

D. 400x



Now click on the link to see the image you selected.

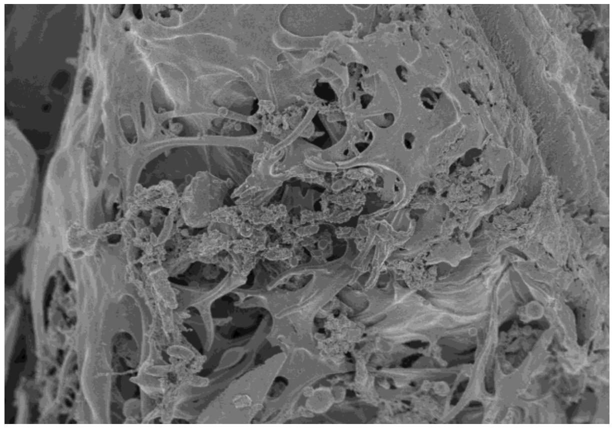
4. Did a round worm make the family sick?
   A. Yes
   B. No

5. Lastly, you are going to look for *Escherichia coli* (*E. Coli*) bacteria. This is also elongated in shape but 1μm long. What is this size in meters? [There is a hint for converting units]
   A. 10^{-3} m
   B. 10^{-4} m
   C. 10^{-5} m
   D. 10^{-6} m

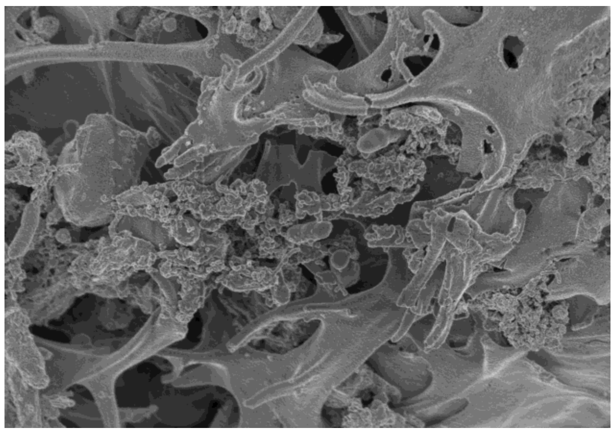
6. What instrument would you like to use to image the sponge to look for the bacterium? The resolution of the instruments is given. [There is a hint to describe the instruments.]
   A. Hand scope or optical microscope
   B. Scanning electron microscope

7. What magnification would you like to see? [There is a hint to describe how to determine a magnification.]

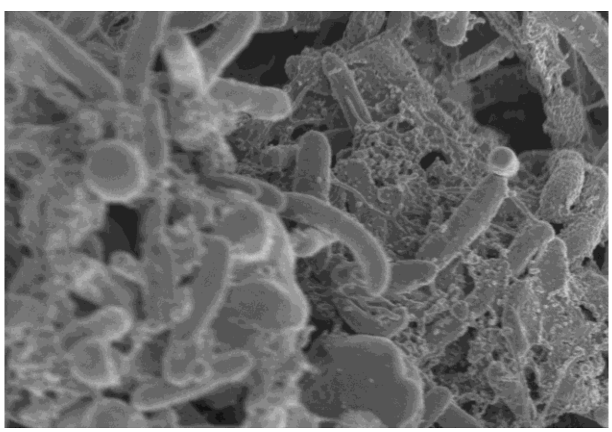
A. 5000x



B. 10 000x



C. 15 000x



Now click on the link to see the image you selected

8. Did a bacterium make the family sick?
   A. Yes
   B. No

9. Comparing a round worm (0.1 mm long) and a bacterium (1 μm long), which is longer and by how much? [There is a hint for converting units]
   A. A round worm is 100x longer
   B. A round worm is 1000x longer
   C. A bacterium is 10x longer
   D. A bacterium is 100x longer

10. The size of a round worm (10^{-4} m) and bacterium (10^{-6} m) added together would equal [There is a hint for using exponents]
    A. 10^{-4} m because the round worm is much bigger.
    B. 10^{-6} m because the bacterium is much bigger.
    C. 10^{-10} m because the sum of the two sizes makes a much smaller size.

Scoring: (1 point each) 6 -10 (>=60%) – move on

0-5 (<60%) – repeat with a note to make sure to check the hints.

Scenario 1 Questions:

1. Number sense
2. Converting
3. Conceptualizing relative sizes
4. Use of units
5. Visualizing scales

Scoring: *1 point each*

5 (100%) – Scenario 3 3-4 (>=60-85%) – Scenario 2 0-2 (<60%) repeat

---

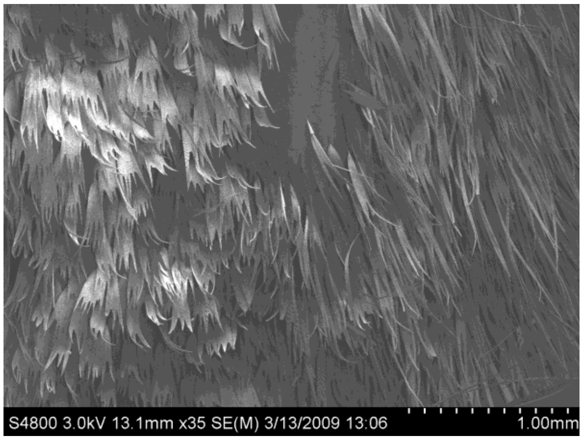
Scenario 2: Introduction

On a recent trip, you discover a species of plant that appears to spread its pollen by the activity of a common moth. You have a sample of a moth wing and need to identify whether the pollen is on the wing. To do this, you will need to verify the presence of the pollen and determine the size of the pollen. Only by comparing the size and shape to another known sample will you be able to conclude that the pollen is the same. Please use the hints provided as they are designed to help you with answering the questions. Good luck!

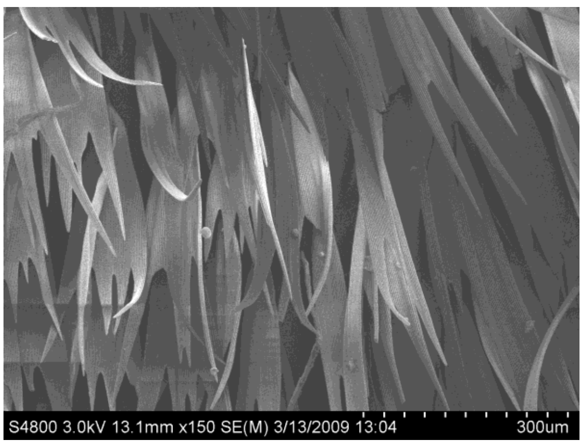
1. First view the images generated from the scanning electron microscope. [Link to the movie] Does there appear to be pollen on the moth wing?

A. Yes
B. No

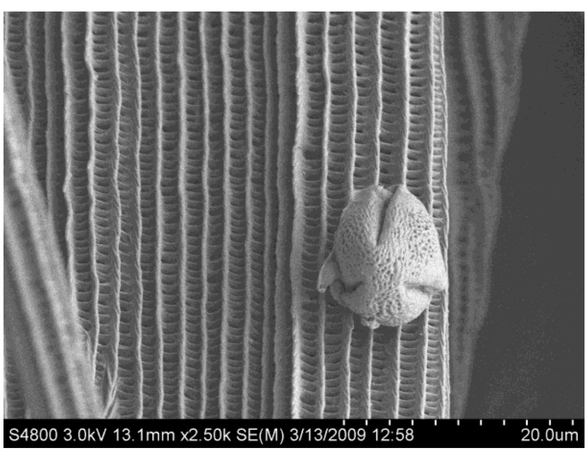
2. What magnification would you like to view to be able to measure the pollen?
A. 35x



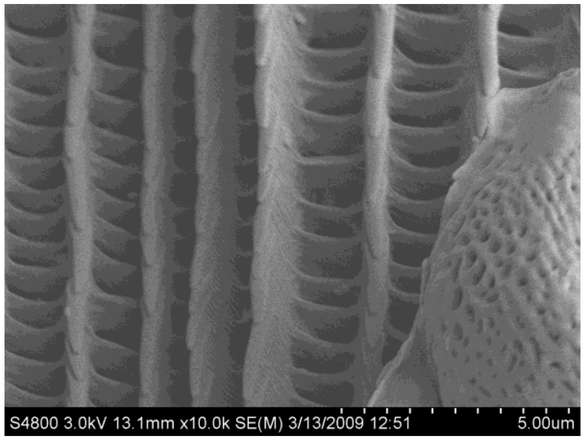
B. 150x



C. 2500x



D. 10 000x

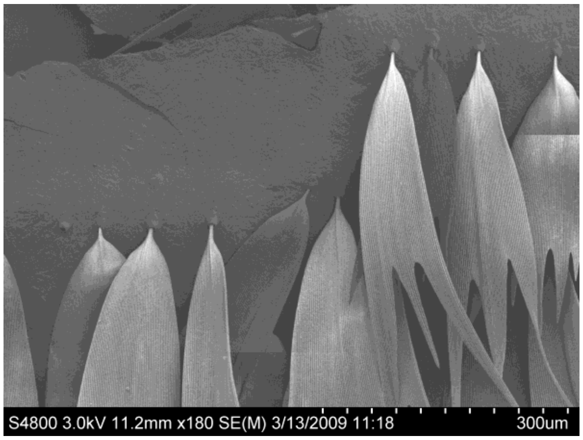


(Only after they select, then they go to the link and view the image)

3. The image size is 12 cm. Using the image that shows the pollen, how big is the pollen?
   OR? Could grade on a range (0.000001 +/- 0.0000015 thus allowing for 8.5 µm to 11.5 µm (answer is ~9.6))? (Then not multiple choice…)
   Otherwise:
   A. 4.8 mm
   B. 0.10 mm
   C. 48 µm
   D. 10 µm

4. If the pollen from the new plant species is 10 µm in size, could this be pollen from the new plant species?
   A. Yes
   B. No

5. If the size of pollen is 10 µm, what is this size in meters?
   A. 10^{-4} m
   B. 10^{-5} m
   C. 10^{-6} m
   D. 10^{-7} m
6. The small units on the moth wing are called feathers.



If a feather is about 75 μm wide, how much bigger is a feather than the pollen?

A. Less than 10x

B. Between 10x and 100x

C. Between 100x and 1000x

D. More than 1000x

7. If the moth measure 2 cm, how much bigger is a moth than its feathers?

   A. Less than 10x

   B. Between 10x and 100x

   C. Between 100x and 1000x

   D. More than 1000x

8. The size of the moth (10^{-2} m) and pollen (10^{-5} m) added together would equal

   A. 10^{-2} m because the moth is much bigger.

   B. 10^{-5} m because the pollen is much bigger.

   C. 10^{-7} m because the sum of the two sizes makes a much smaller size.

   [There is a hint for using exponents]

Scoring: (1 point each) 5 -8 (>60%) – move on

0-4 (<60%) – repeat with a note to make sure to check the hints.

Scenario 2 Questions:

1. Number sense
2. Conceptualizing relative sizes
3. Calculating magnifications
4. Visual spatial skills
5. Visualizing scales

Scoring: *1 point each*

4-5 (>=80%) – Scenario 3 0-3 (<80%) repeat

Scenario 3: Introduction

In a local park, a crime has been committed; however, there is evidence that the current location in the park is not the original crime scene. The park is several hundred acres and would take hours to search. But this park is unique that there are some very distinct areas in the park that contain only certain types of plants. It was noted that there appeared to be some pollen on the clothes and that this could narrow down the potential area for the original crime scene. Your job is to identify the pollen on the clothes and determine which strain of plant it belongs to and therefore the area in the park to search. Please use the hints provided as they are designed to help you with answering the questions. Good luck!

1. First view the image generated from the scanning electron microscope of the pollen from the clothing. What magnification is the image taken at?

2. Using the magnification, and if the size of the image is 12 cm, what size is the unknown pollen?

3. In the park there are 4 areas that contain 4 distinct plant types. View the image for each plant type to determine which plant is a match. Check the one(s) that you can <u>eliminate</u> based solely on visual characteristics.
   A. Goldenrod
   B. Ragweed
   C. Hibiscus
   D. Weavers
   E. Malva

4. Determine the pollen size for the Hibiscus?
5. Determine the pollen size for the Ragweed?

6. Determine the pollen size for the Weavers?

7. Identify which pollen you have determined the unknown pollen to be?

    a. Hibiscus

    b. Ragweed

    c. Weavers

8. If we had a sample that contained all 5 pollens, which would appear the largest?
    A. Goldenrod
    B. Ragweed
    C. Hibiscus
    D. Weavers
    E. Malva

9. If we were to look at that sample using a hand lens with a magnification of 10x, select all that would be visible. (The threshold for the unaided eye is 0.1 mm)
    A. Goldenrod
    B. Ragweed
    C. Hibiscus
    D. Weavers
    E. Malva

Scoring: (1 point each) 5 -8 (>60%) – move on

0-4 (<60%) – repeat with a note to make sure to check the hints.

Scenario 3 Questions:

Scoring: *1 point each*

4-5 (>=80%) – Scenario 3 0-3 (<80%) repeat

Unitizing/Anchoring Activity

Initial Activity Questions:

9. Comparison drawings – Scale test (macroscopic) – level 1
10. CPS / density – level 1
11. CPS / macroscopic/particle representations - level 1
12. CPS or scale pretest / comparison (particulate level) – level 2
13. Compound, element – particulate drawing (Scale test) – level 2
14. Definition (scale pretest) – level 3
15. CPS / Misconception statements – level 3
16. Properties of particles (scale pretest) – level 3

Scoring: 7-8 (>=75%) – high 5-6 (50-75%) – medium 0-4 (<50%) – low

---

Scenario 1: **Introduction**

Although you may have done something very similar in lecture, you are going to continue to examine the relationship between macroscopic and particulate representations. You will use this to discuss properties (function) and how this relates to structure. For this first activity, you will continue to examine graphite and consider the property of graphite, lubrication.

Please use the hints provided as they are designed to help you with answering the questions. Good luck!

11. On a macroscopic scale, what is/are **not** visible?
    [Hint: Definition of macroscopic scale]

    Inserted Hint:
    When something is described as "at the macroscopic" scale or level, it refers to bulk matter or many, many atoms in the sample. Macroscopic can be visible to the unaided eye but is not a requirement.

    I. Atoms
    II. Molecules

    a. Both I and II
    b. Only I
    c. Only II
    d. Neither I nor II

12. In chemistry, what identifying characteristic **defines** a particle-level representation or image?
    [Hint: particle-level representations]
    Inserted hint:
    Consider the images in your textbook. Many times you can view something where individual atoms are integrated into the image. Images that give you atomic resolution are intended to help you think about matter on the particle-level. In chemistry these particles are very often atoms or molecules.

    a. Observing state of matter in the representation
    b. Observing atoms or molecules in the representation
    c. Observing the mass of the matter in the representation

   d. Observing the density of the matter in the representation

13. What is a good description of a good lubricant on a macroscopic-level? (Select all that are correct)
    a. Bumpy
    b. Coarse
    c. Silky
    d. Slick

14. In order to view the why graphite would be a good lubricant on the **macroscopic-level**, which instrument would you like to use to image the graphite? Click on the image once you have selected which instrument to use.
    [Hint available for the different types of instruments and their magnifications]

    Inserted hint:
    (add STM)
    a. Hand scope or optical microscope (once you select this, click here to view this image)
    b. Scanning electron microscope (once you select this, click here to view this image)
    c. Scanning tunneling microscope (once you select this, click here to view this image)

15. What is a good description of a good lubricant on a particle-level? (Select all that are correct)
    [Hint available for thinking about this property on the particle-level]

    Inserted hint:
    In order to have something that is smooth or slick, something on the particle-level must be structured to let particles slide past one another. This cannot involve the breaking of many chemical bonds but would involve the molecules or particles easily passing by each other.
    a. Lines of particles
    b. Sheets of particles
    c. Branched particles
    d. Large bonded masses of particles

16. In order to view the why graphite would be a good lubricant on the **particle-level**, which instrument would you like to use to image the graphite? Click on the image once you have selected which instrument to use.
    [Hint available for the different types of instruments and their magnifications]

    Inserted hint:
    (add STM)
    a. Hand scope or optical microscope (once you select this, click here to view this image)

b. Scanning electron microscope (once you select this, click here to view this image)
c. Scanning tunneling microscope (once you select this, click here to view this image)

17. Compare the images you used for viewing the properties on the macroscopic and particle-level (numbers 4 and 6). Which statements are true?
    [Hint: Look back at the images if you need to]
    I. The SEM image shows the sheets of graphite but not carbon atoms.
    II. The STM image shows one sheet of graphite magnified enough to image the carbon atoms.
    a. Both I and II
    b. Only I
    c. Only II
    d. Neither I nor II

18. Identify the area of the STM image from the figure of graphite.
    Insert figure
    [Hint: Look back at the STM image if you need to – what are the "bumps" in the image?]
    a. Either A or B
    b. Only A
    c. Only B
    d. Neither A not B

Scoring: (1 point each) 4 -8 (>=50%) – move on
0-3 (<50%) – repeat with a note to make sure to check the hints.

Scenario 1 Questions:

1. Comparison drawings – Scale test (macroscopic) – clone I
2. CPS / density
3. CPS / macroscopic/particle representations
4. CPS or scale pretest / comparison (particulate level)

Scoring: *1 point each*
4 (100%) – Scenario 3 2-3 (>=50-75%) – Scenario 2 0-1 (<50%) repeat

---

Scenario 2: Introduction

As we continue to discuss macroscopic properties that we observe and particle properties that guide us to explain these observations, we will begin to see how "function" (macroscopic behavior) follows "structure" (particle properties). In this next activity, we will investigate what happens on a particle-level when we observe certain properties.

Please use the hints provided as they are designed to help you with answering the questions. Good luck!

9. Two sheets of graphite are shown. What is the direction of the "slide" that allows for graphite to be a good lubricant?
   Insert figure
   [Hint: Covalent bonds versus intermolecular attractions]

   Insert hint:
   Covalent bonds are intramolecular forces or show the sharing of electrons in a single molecule. Intermolecular forces are the interactions between the molecules. Covalent bonds are stronger and closer (shorter) than intermolecular attractions (which are weaker and longer).
   a. Both A and B
   b. Only A
   c. Only B
   d. Neither A nor B

10. Where are the covalent bonds in the drawing of graphite (shown in the figure)?
    Insert figure
    [Hint: Representing covalent bonds in particulate drawings]

    Inserted Hint:
    Covalent bonds are shown in ball and stick models with solid lines. These bonds are shorter than intermolecular attractions. Intermolecular attractions can be represented with dashed lines (or just spaces) and are longer and weaker than covalent bonds.
    a. Both A and B
    b. Only A
    c. Only B
    d. Neither A nor B

11. Graphite is a good lubricant. On the particle-level, what is broken or overcome in order for graphite to be a good lubricant? Use the drawing to help you answer.
    Insert figure
    [Hint: Covalent bonds versus intermolecular attractions]

    Insert hint:
    Covalent bonds are intramolecular forces or show the sharing of electrons in a single molecule. Intermolecular forces are the interactions between the molecules. Covalent bonds are stronger and closer (shorter) than intermolecular attractions (which are weaker and longer).
    a. covalent bonds
    b. intermolecular attraction

12. Carbon can also exist as diamond. Diamond has a very different structure from graphite. The representation of diamond is shown to the right. Would you predict that diamond would be a good lubricant?
    Insert figure
    [Hint available for thinking about lubrication on the particle-level]

    Inserted hint:
    In order to have something that is smooth or slick, something on the particle-level must be structured to let particles slide past one another. This cannot involve the breaking of

many chemical bonds but would involve the molecules or particles easily passing by each other.

a. Yes
b. No

13. If diamond would be a good lubricant, what would need to be broken in order for pieces of diamond to "slip" past one another like in graphite?
    a. Covalent bonds
    b. Intermolecular attractions

14. Both diamond and graphite are made of only carbon. Comparing the two representations of diamond and graphite, would the carbon atoms be the same size?
    Insert figures
    a. Yes
    b. No

15. Which of the properties of carbon are macroscopic? (Select all that are correct)
    [Hint: what makes a property a macroscopic property/what makes a property a particle property]

    Inserted hint:
    A macroscopic property (like a macroscopic image) is one of the bulk material. It would make sense to talk about the state of a substance if you have many, many atoms – hence state is a macroscopic property. However, without other atoms, you would not be able to define the state of a substance – hence state is not a particle-level property. Other macroscopic properties include color and density.
    a. Black in color
    b. Solid at room temperature
    c. Bonds with oxygen to make CO
    d. Requires energy to remove an electron

16. Which of the properties of oxygen are particle-level? (Select all that are correct)
    [Hint: Particle-level properties]

    Inserted hint: For a property to be a particle-level property, it must be true for a single particle. We cannot define state for a single particle so state is not a particle-level property. We can discuss a reaction on the particle-level, so the ability of something to react can be a particle-level property. Additionally, properties of single particles (single molecules) would be particle-level properties, such as oxygen molecules contain a double bond.
    a. Boils at 90 K
    b. Diatomic element
    c. Has a density of 1.43 $g \cdot L^{-1}$
    d. Reacts with nitrogen to form NO

17. Oxygen molecules and carbon monoxide molecules are **approximately** the same size.
    a. True
    b. False

Scoring: (1 point each) 5 -9 (>50%) – move on
0-4 (<50%) – repeat with a note to make sure to check the hints.

Scenario 2 Questions:

1. Comparison drawings – Scale test (macroscopic) – clone II
2. CPS or scale pretest / comparison (particulate level) – clone of pretest
3. Compound, element – particulate drawing (Scale test) – clone I
4. Properties of particles (scale pretest)

Scoring: *1 point each* 3-4 (>=75%) – Scenario 3 0-2 (<75%) repeat

---

Scenario 3: **Introduction (in the instruction section)**
In this last activity, we will take the idea of function and structure and extend this into boiling point. How does structure affect boiling point? How does size or scale affect boiling point?
Please use the hints provided as they are designed to help you with answering the questions. Good luck!

1. Which macroscopic figure best shows a substance boiling?
[Hint: Phase change on the macroscopic level]

   Inserted hint:
   To identify this, you need to look for two things: the correct macroscopic representation of the states and the correct phase transition. How are solids, liquids and gases represented on the macroscopic-level?
   Insert figures

2. Which particle-level figure best shows a substance boiling?
[Hint: Phase change on the particle level]

   Inserted hint:
   To identify this, you need to look for two things: the correct particle representation of the states and the correct phase transition. How are solids, liquids and gases represented on the particle-level?

   Insert figures

3. A sample of water has been boiling for 5 minutes. What is in the bubbles that continue to form in the liquid water?
   a. Air molecules
   b. H_2O molecules
   c. H atoms and O atoms
   d. H_2 molecules and O_2 molecules

4. What happens when a substance boils?
   a. The covalent bonds in the molecule are broken.
   b. The intermolecular attractions between the molecules are overcome.
   c. The molecules get bigger and bigger until they enter the gas phase.

d. All of these things occur.

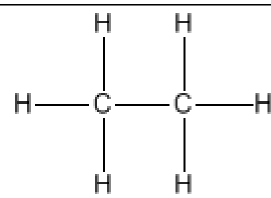
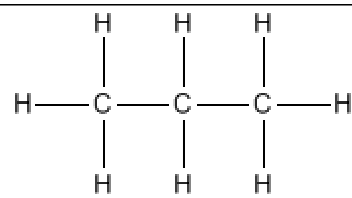
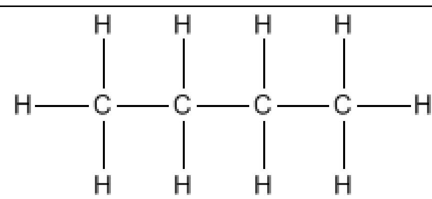
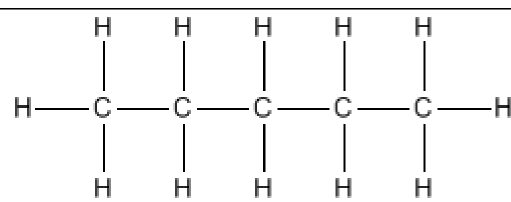
5. Where are the intermolecular attractions on the diagram of hydrogen fluoride (shown)? [Hint: Representing covalent bonds in particulate drawings]

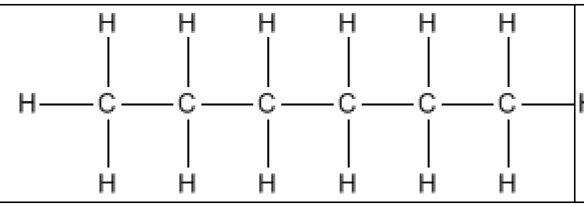
Inserted Hint:
Covalent bonds are shown in ball and stick models with solid lines. These bonds are shorter than intermolecular attractions. Intermolecular attractions can be represented with dashed lines (or just spaces) and are longer and weaker than covalent bonds.

Insert figure

a. Both A and B
b. Only A
c. Only B
d. Neither A nor B

6. The series for the boiling point for hydrocarbons are given in the table. How are the structures of the hydrocarbons similar?

Name	Formula	Structure	Boiling point	State at room temperature
ethane	C_2H_6		–89°C	Gas
propane	C_3H_8		–42°C	Gas
butane	C_4H_{10}		–0.5°C	Gas
propane	C_5H_{12}		36°C	Liquid

hexane	C_6H_{14}		69^{o}C	Liquid

I. They are contain only carbon and hydrogen
II. They all have only single C-C bonds.

a. Both I and II
b. Only I
c. Only II
d. Neither I nor II

7. How are they different?
   I. They contain a differing number of carbon and hydrogen atoms
   II. They are getting bigger
   a. Both I and II
   b. Only I
   c. Only II
   d. Neither I nor II

8. What is the effect of size on boiling point of similarly structured molecules? As molecules get larger,
   [Hint: Intermolecular forces and size of similar molecules]

   Inserted hint:
   As molecules get larger, they have more electrons that can interact more with other molecules. Therefore the intermolecular forces increase. As intermolecular forces increase, it takes more energy to overcome these forces. Temperature is a measure of this average energy. Therefore another way to say this – as intermolecular forces increase, the boiling point increases.
   a. the intermolecular forces and the boiling points increase.
   b. the intermolecular forces increase and the boiling points decrease.
   c. the intermolecular forces decrease and the boiling points increase.
   d. the intermolecular forces and the boiling points decrease.

9. Although molecules are not visible to the unaided eye, are all molecules the same size?
   a. Yes
   b. No

10. Is it important to consider the size of a molecule in relation to other molecules?
    a. Yes
    b. No

Scoring: (1 point each) 5 -9 (>50%) – move on
0-4 (<50%) – repeat with a note to make sure to check the hints.

Scenario 3 Questions:

1. CPS / macroscopic/particle representations

2. CPS or scale pretest / comparison (particulate level) – clone II
3. Compound, element – particulate drawing (Scale test) – clone I
4. CPS / Misconception statements

Scoring: *1 point each*
3-4 (>=75%) – Final questions 0-2 (<75%) repeat

Final Questions:

1. Comparison drawings
2. CPS or scale pretest / comparison
3. Compound, element – particulate drawing
4. Definition
5. Properties of particles

Hints

Converting Units Hint

When converting prefixed units to the base unit such as in this example you are going from the prefixed unit mm to m, it will take two ideas. First you must determine what the exponential value is of the prefix and then determine what the exponential value is of the number. Then use your rules for multiplying numbers with exponents to determine the final answer. Look at the example below...

100 ng to g

n=nano and nano- is 10^{-9}, so we can express it as 100 x 10^{-9}g.

Then 100 is 10^{2}, so once again we can again re-express the value in another way...

10^{2} x 10^{-9} g

by applying the rules for multiplying numbers with exponents we get...10^{-7} g

because $10^{2} \times 10^{-9} = 10^{2+-9} = 10^{-7}$ g

So to compare two sizes, it is easier to obtain a ratio. For example: a football field is 0.1 km long and an ant is 1 cm long. In order to compare, first the units must be the same:

0.1 km = 0.1 x 1000 m = 100 m

1 cm = 1 x 0.01 m = 0.01 m

Then compare by dividing the larger object by the smaller object:

(100 m)/(0.01 m)=10,000

Therefore, we would say a football field is 10,000x bigger than an ant.

Instrument Hint

A hand scope or optical microscopes utilize glass lenses to magnify the object to an image size that our eyes can resolve. Hand scopes such as a magnifying lens, only uses 1 lens and is limited by the focal length of that lens. An optical microscope utilizes two or more glass lenses to magnify the object to an image size that our eyes can resolve. Because it utilizes a combination of two lenses, the magnifications can be much larger by combining the magnifications of each lens by multiplying the values to a final magnification. Because each of these microscopes utilize light reflecting off of the object in order to see the object, they are limited by the wavelengths of light regardless of the number of lenses are used. This means that objects can be too small to resolve with these.

A scanning electron microscope (SEM) utilizes an electron beam. The electrons are "shot" at the object and then the electrons coming off of the object are captured and appear as an image on an output screen. Since electrons are much smaller than the wavelengths of light, many objects that can't be resolved using an optical microscope can be resolved using an SEM.

The resolution therefore refers to the magnification possible for each instrument. Magnification can be expressed as:

original size x magnification = magnified size

In order to be visible, an object needs to be at least 0.1 mm (the threshold for our eyes). So if an object that is 1 nm long is magnified 100,000x by using an SEM:

$$1 \text{ nm} \times 100{,}000 = 100{,}000 \text{ nm}$$

$$\text{or } 1 \times 10^{-9} \times 100{,}000 = 1 \times 10^{-4} \text{ m} = 0.1 \text{ mm}$$

it would just be visible. Usually it is desired for an image size to be at least 1 cm long since 0.1 mm is the minimum size our eyes can resolve and can be barely seen.

A scanning tunneling microscope (STM) uses a very fine wire that has a very fine tip (so fine in fact, it ideally only has 1 atom at the very tip) to sense the location of individual atoms. An electrical circuit that runs through the sample and through the tip is set up and a tunneling current is measured between the atoms of the sample and the tip. As the distance between the tip and part of the atom changes, the measured values “sketch” out the location of the individual atoms. Because the sensing of the atoms is through the tip, the tip shape determines the resolution of an STM. Therefore if there is only one atom at the tip, the resolution of the STM could be on the order of 1 Å or the approximate diameter of an atom. (The wedge size of the tip is a major factor, however, I am not sure how to phrase this….the fatter the wedge, the lower the resolution)

Magnification Hint

A magnification is a ratio of the actual size of an object to the apparent size of the object after it has been magnified. You can also utilize the lenses to determine the final possible magnification by multiplying the magnifications by each lens.

original size x magnification = magnified size

But if you don't know where to start for lenses, you can determine what minimum magnification you need by comparing the object's actual size with the minimum resolution size of our eyes, 0.1 mm.

So, if an object has an actual size of 1 nm and using the resolution of our eye as 0.1 mm we would first put them into common units (doesn't matter what unit), so for ease, let's go to meters.

So….

$$1 \text{ nm} = 1 \times 10^{-9} \text{ m}$$

$$0.1 \text{ mm} = 1 \times 10^{-4} \text{ m}$$

magnification=(magnified size)/(original size)

$$\text{magnification}=(1 \times 10^{-4} \text{ m})/(1 \times 10^{-9} \text{ m})=1 \times 10^{5} \textit{ or } 100{,}000\text{x}$$

is the minimum magnification needed to view the object.

So, 10^{-9}m for the object and 10^{-4} for the eye resolution. So, $10^{-4}/10^{-9} = 10^{5}$ magnification is needed which can also be expressed as 100,000x.

Magnification Hint

Rules of Exponents:

$$a^m \bullet a^n = a^{m+n}$$

If the bases of the exponential expressions that are multiplied are the same, then you can combine them into one expression by adding the exponents.

This makes sense when you look at

$$2^3 \bullet 2^4 = (2 \bullet 2 \bullet 2) \bullet (2 \bullet 2 \bullet 2 \bullet 2) = 2^7$$

$$\frac{a^m}{a^n} = a^{m-n}$$

If the bases of the exponential expressions that are divided are the same, then you can combine them into one expression by subtracting the exponents.

This makes sense when you look at

$$\frac{x^7}{x^3} = \frac{x \bullet x \bullet x \bullet x \bullet \cancel{x} \bullet \cancel{x} \bullet \cancel{x}}{\cancel{x} \bullet \cancel{x} \bullet \cancel{x}} = x \bullet x \bullet x \bullet x = x^4$$

$$(a^m)^n = a^{m \bullet n}$$

When you have an exponential expression raised to a power, you have to multiply the two exponents.

This makes sense when you look at

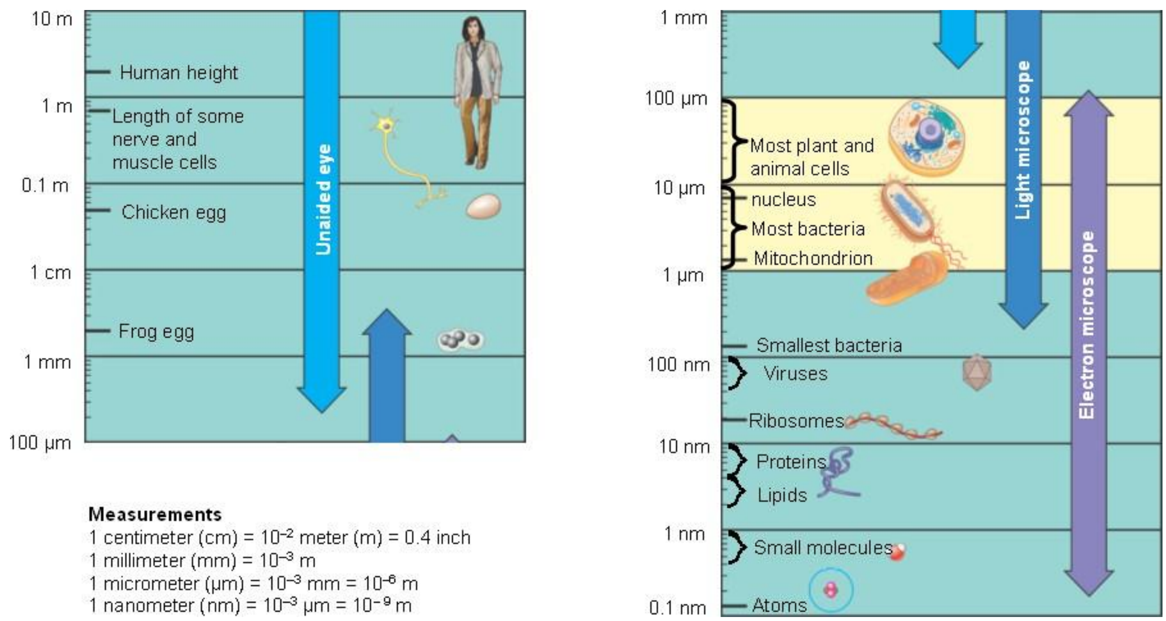
$$(3^2)^3 = 3^2 \bullet 3^2 \bullet 3^2 = 3^{2+2+2} = 3^6$$

Notice that we had to use another rule of exponents to help us make sense of this rule. This is a common occurrence. Many times you will use more than one rule of exponents when working problems.

Scale Activity – Supplemental Handout

Scale of sizes

The range of sizes from human size down to the atomic level extends from 1 m to 10^{-10} m.



Number Sense

Rules for exponents:

To add two values, the exponents must be the same:

$$10^{-3} + 10^{-5} = 1\times10^{-3} + 1\times10^{-5} = 100\times10^{-5} + 1\times10^{-5} = 101\times10^{-5} \approx 100\times10^{-5} = 10^{-3}$$

To subtract two values, the exponents must also be the same:

$$10^{-2} - 10^{-4} = 1\times10^{-2} - 1\times10^{-4} = 100\times10^{-4} - 1\times10^{-4} = 99\times10^{-4} \approx 100\times10^{-4} = 10^{-2}$$

To multiply two values, the coefficient is multiplied and the exponents are added:

$$10^{-2} \times 10^{-4} = 1\times10^{-2} \times 1\times10^{-4} = 1\times10^{(-2 + -4)} = 1\times10^{-6} = 10^{-6}$$

To divide two values, the coefficients are divided and the exponents are subtracted:

$$10^{-3} / 10^{-6} = 1\times10^{-3} / 1\times10^{-6} = 1\times10^{(-3 - -6)} = 1\times10^{(-3 + 6)} = 1\times10^{3} = 10^{3}$$

Converting Units

When converting prefixed units to the base unit, first you must determine what the exponential value is of the prefix and then determine what the exponential value is of the number. Then use your rules for multiplying numbers with exponents to determine the final answer.

For example: Convert 100 ng to g n = nano and nano = 10^{-9}

Now we can express it as 100 x 10^{-9}g.

100 = 10^2, we can re-express the value as 10^2 x 10^{-9} g

By applying the rules for multiplying numbers with exponents:

$$10^2 \text{ x } 10^{-9} = 10^{2+-9} = 10^{-7} \text{ g}$$

To compare two sizes, it is easier to obtain a ratio.

For example: Compare the size of a football field is 0.1 km long to an ant is 1 cm long. In order to compare, first the units must be the same:

0.1 km = 0.1 x 1000 m = 100 m   1 cm = 1 x 0.01 m = 0.01 m

Then compare by dividing the larger object by the smaller object:

$$\frac{100 \text{ m}}{0.01 \text{ m}} = 10{,}000$$

Therefore, we would say a football field is 10,000x bigger than an ant.

If we added the size of the football field to the size of the ant, the sum would be equal to the size of the football field. Again using the lengths:

$$10^2 \text{ m (football field)} + 10^{-2} \text{ m (ant)} = 1 \times 10^2 + 0.0001 \times 10^2 \text{ m}$$
$$= 1.0001 \times 10^2 \text{ m} \approx 10^2 \text{ m}$$

This shows that when two very different sized objects are compared, only one overwhelmingly contributes to the size of both.

Instrumentation information

A **hand scope or optical microscope utilize** glass lenses to magnify the object to an image size that our eyes can resolve. Hand scopes such as a magnifying lens, only uses 1 lens and is limited by the focal length of that lens. An optical microscope utilizes two or more glass lenses to magnify the object to an image size that our eyes can resolve. Because it utilizes a combination of two lenses, the magnifications can be much larger by combining the magnifications of each lens by multiplying the values to a final magnification. Because each of these microscopes utilize light reflecting off of the object in order to see the object, they are limited by the wavelengths of light regardless of the number of lenses are used. This means that objects can be too small to resolve with these.

A **scanning electron microscope (SEM)** utilizes an electron beam. The electrons are "shot" at the object and then the electrons coming off of the object are captured and appear as an image on an output screen. Since electrons are much smaller than the

wavelengths of light, many objects that can't be resolved using an optical microscope can be resolved using an SEM.
The resolution therefore refers to the magnification possible for each instrument.

A **scanning tunneling microscope (STM)** uses a very fine wire that has a very fine tip (so fine in fact, it ideally only has 1 atom at the very tip) to sense the location of individual atoms. An electrical circuit that runs through the sample and through the tip is set up and a tunneling current is measured between the atoms of the sample and the tip. As the distance between the tip and part of the atom changes, the measured values "sketch" out the location of the individual atoms. Because the sensing of the atoms is through the tip, the tip shape determines the resolution of an STM. Therefore if there is only one atom at the tip, the resolution of the STM could be on the order of 1 Å or the approximate diameter of an atom. In meters, this is 10^{-10} m (100 pm).

What is Magnification?

Changing the size of an object is called magnification. The magnification value is how many times one can fit across another. This can be represented using an equation:

actual size x magnification = new size

$$\frac{\text{new size}}{\text{actual size}} = \text{magnification}$$

Magnifications that are greater than 1 make things appear bigger than they really are while magnifications less than 1 (reductions) makes things appear smaller than they really are.

You can determine what minimum magnification you need by comparing the object's actual size with the minimum resolution size of our eyes, 0.1 mm.

For example: If an object has an actual size of 1 nm and using the resolution of our eye as 0.1 mm we would first put them into common units (doesn't matter what unit), for ease, let's go to meters.

1 nm = 1 x 10^{-9} m 0.1 mm = 1 x 10^{-4} m

$$\text{magnification} = \frac{\text{magnified size}}{\text{original size}}$$

$$\text{magnification} = \frac{1\times10^{-4}\ \text{m}}{1\times10^{-9}\ \text{m}} = 1\times10^{5} \text{ or } 100,000x$$

is the minimum magnification needed to view the object. It would just be visible. Usually it is desired for an image size to be at least 1 cm long since 0.1 mm is the minimum size our eyes can resolve and can be barely seen.

Another way to think about this is: 10^{-9}m is the size of the object and 10^{-4} is the size of our eye resolution. So, $10^{-4}/10^{-9} = 10^{5}$ magnification is needed (which can also be expressed as 100,000x).

You can also move from one magnification to another, the process is the same as above

$$\frac{new\ magnification}{original\ magnification} = magnification\ change\ factor$$

When we have a factor of 10^{x}, it is referred to as an order of magnitude.

$1000 = 1 \times 10^{3} = 10^{3}$ $x = 3$ 3 orders of magnitude

Magnifications and orders of magnitude help us relate small or large objects back to a visible or usable size. For example, a virus is 7 orders of magnitude smaller than a human. If a virus was the size of a human, it would have to magnified 10^{7} times or 10 000 000 (10 million times) times. That also means that 10 million viruses lined up end to end would be the height of 1 m.

Lastly, if we are on the level of one object that is vastly different in size from another, we can see one without seeing the other.

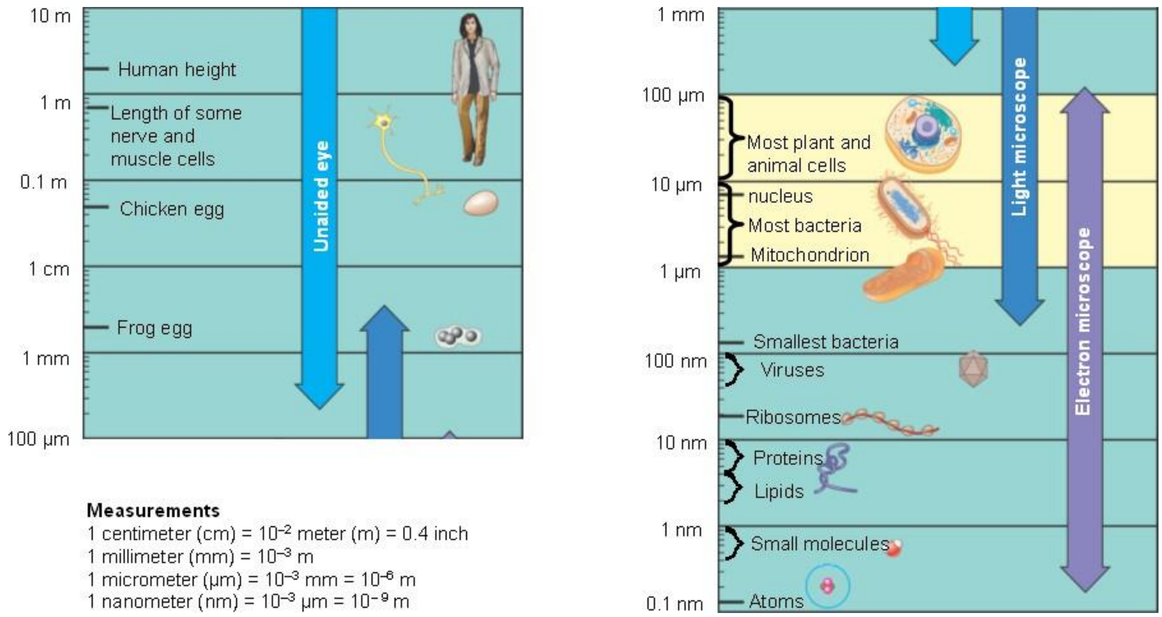
This means that if we are looking for viruses compared to ourselves, we would never see a virus – it is much too small. If we imaged a virus on someone’s fingernail, we would see the virus (now at a magnification of 100,000 times to get the virus to a size of 1 cm), we would not see the human holding the virus.

Back to the example of the football field. If you were focusing in on the ant, you would not see the entire football field. If you could see the entire football field, you couldn’t see an ant on the football field.

Unitizing/Anchoring (Macroscopic vs Particle) – Supplemental Handout

Scale of sizes

The range of sizes from human size down to the atomic level extends from 1 m to 10^{-10} m.



We observe on the macroscopic level. This is due to its structure on the particle level – we explain the macroscopic observations on the particle level.

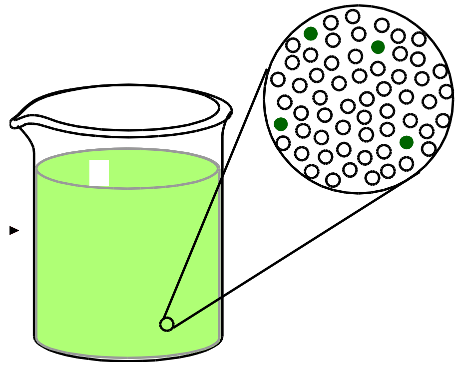
Macroscopic

When something is described as "at the macroscopic" scale or level, it refers to bulk matter or many, many atoms in the sample. Macroscopic can be visible to the unaided eye but is not a requirement.

A macroscopic property (like a macroscopic image) is one of the bulk material. It would make sense to talk about the state of a substance if you have many, many atoms – hence state is a macroscopic property. However, without other atoms, you would not be able to define the state of a substance – hence state is not a particle-level property. Other macroscopic properties include color and density.

To identify this, you need to look for two things: the correct macroscopic representation of the states and the correct phase transition. How are solids, liquids and gases represented on the macroscopic-level?

An example of a macroscopic and particle-level is shown to the right. The macroscopic image shows a property of the bulk (phase is liquid, the solution has color, the solution has a density of some amount, etc).



The particle image (described below) shows particle-level information. More exact particle-level images show structure of molecules (atoms within molecules).

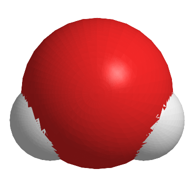
Particles

Consider the images in your textbook. Many times you can view something where individual atoms are integrated into the image. Images that give you atomic resolution are intended to help you think about matter on the **particle-level**. In chemistry these particles are very often atoms or molecules.

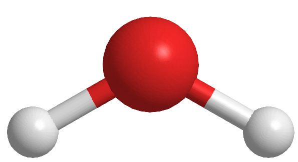
Thinking about properties on the particle-level requires thinking about what structure of the particles would allow for observing a macroscopic property. For example, in order to have something that is smooth or slick, something on the particle-level must be structured to let particles slide past one another. This cannot involve the breaking of many chemical bonds but would involve the molecules or particles easily passing by each other.

For a property to be a particle-level property, it must be true for a single particle. We cannot define state for a single particle so state is not a particle-level property. We can discuss a reaction on the particle-level, so the ability of something to react can be a particle-level property. Additionally, properties of single particles (single molecules) would be particle-level properties, such as oxygen molecules contain a double bond.

Example of particle diagram of a single molecule of water (space-filling model):



Example of particle diagram of a single molecule of water (ball and stick):



We use color in these diagrams to keep the atoms organized by element-type. For example, oxygen is red and carbon is black. This is for our use of the models –

oxygen atoms are not actually red. Your book has a key for these colors in the back cover.

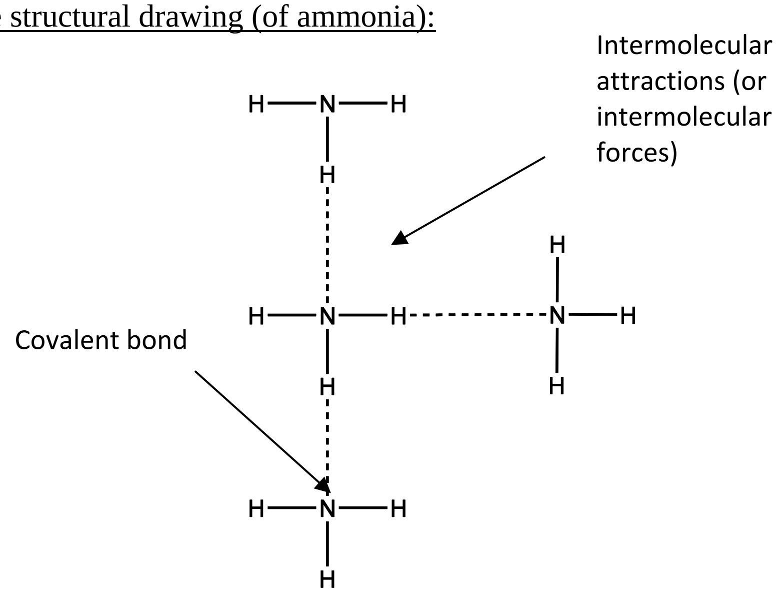
Covalent bonds versus intermolecular attractions

Covalent bonds are intramolecular attractions (or forces) or show the sharing of electrons in a single molecule. Intermolecular attractions (or forces) are the interactions between the molecules. Covalent bonds are stronger and closer (shorter) than intermolecular attractions (which are weaker and longer).

Representing covalent bonds in particulate drawings

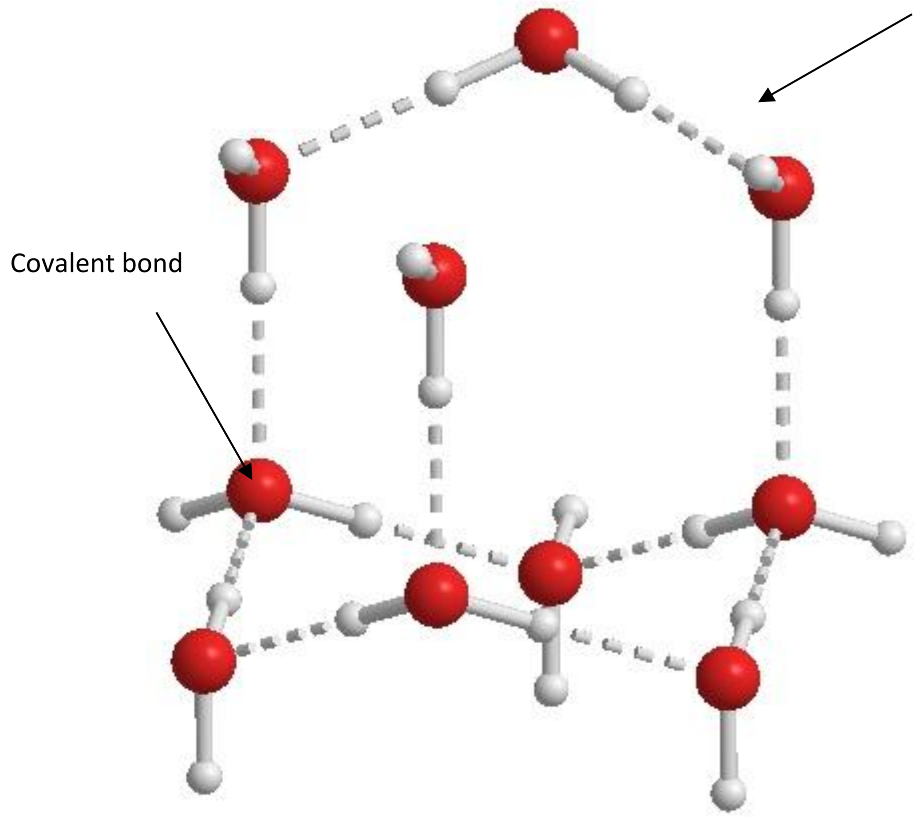
In particulate drawings, covalent bonds are shown in ball and stick models with solid lines. These bonds are shorter than intermolecular attractions. Intermolecular attractions can be represented with dashed lines (or just spaces) and are longer and weaker than covalent bonds.

<u>Particulate structural drawing (of ammonia):</u>



<u>Particulate ball and stick drawing (of water):</u>

Intermolecular attractions (or intermolecular forces)



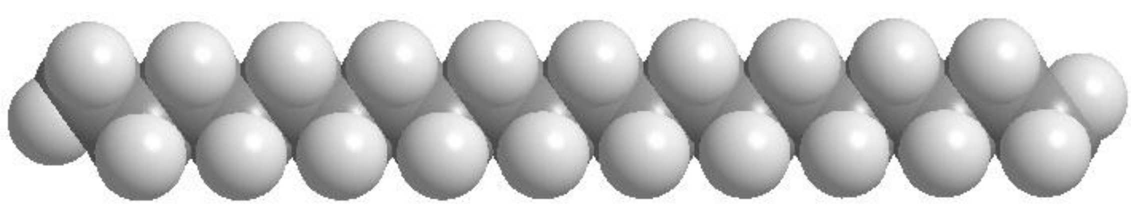
Intermolecular forces and size of similar molecules

As molecules get larger, they have more electrons that can interact more with other molecules. Therefore the intermolecular forces increase. As intermolecular forces increase, it takes more energy to overcome these forces. Temperature is a measure of this average energy. Therefore another way to say this – **as intermolecular forces increase, the boiling point increases**.

Not all molecules are the same size. On the order of molecules – on the size of molecules, different molecules have different sizes and different shapes. A good way to approximate sizes of molecules – atoms are close the same size (although hydrogen is small), so as the number of atoms in the molecules increase, the molecules get larger.

Of course, molecules with the same number of atoms are about the same size.

For example: Compare a large molecule to a small molecule:



($C_{20}H_{42}$)

Compared to methane (CH_4) or water (H_2O):

Which is larger? Which is smaller?

Are methane and water approximately the same size?

Remember this is **not** visible – atoms are on the order of 10^{-10} m or 100 pm. If you can see atomic resolution (definition of individual atoms – like above, finding the carbon, hydrogen and oxygen atoms), then it is very small – many orders of magnitude beyond the resolution of our eyes.