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A Narrative Study of Selected Introductory College Biology Students' Struggles to Gain an Understanding of Scale and Measurement.

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Louisiana State University and Agricultural & Mechanical College

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A NARRATIVE STUDY OF SELECTED INTRODUCTORY COLLEGE BIOLOGY STUDENTS' STRUGGLES TO GAIN AN UNDERSTANDING OF SCALE AND MEASUREMENT

A Dissertation

Submitted to the Graduate Faculty of the Louisiana State University and Agricultural and Mechanical College in partial fulfillment of the requirements for the degree of Doctor of Philosophy

in

The Department of Curriculum and Instruction

by

Juliana G. Hinton
B.S., McNeese State University, 1970
M.Ed., McNeese State University, 1976
December, 2000
ACKNOWLEDGMENTS

The completion of this study is due to the encouragement and assistance of many people. Knowing that my family wished for my success in this endeavor was one of the forces which remained embedded in my mind. There were numerous faculty members, however, both at Louisiana State University (LSU) and McNeese State University (MSU), who were instrumental in my success.

My committee members, Dr. William Doll, Dr. Petra Munro, Dr. William Pinar, and Dr. James Wandersee, seemed to always be available for pouring over materials and pointing out useful approaches when I needed them. Each of their classes that I attended provided invaluable inspiration to spur me on. It was from their tutelage that I gleaned information for this research. My major professor, Dr. James Wandersee is the person whom I credit for offering advice as I strove to complete my dissertation. His recognition of my intense interest and respect prompted him to introduce me to Cynthia Henk, an LSU electron microscopist. She gave me the opportunity to work with the transmission and scanning electron microscopes while I was at LSU.

At MSU support was available at every level—from being granted a sabbatical by the administration, proofing drafts, and having a computer to take to LSU each summer. The following persons helped me in this accomplishment: Dr. Mark Wygoda, Dr. Robert Maples, Dr. Mark Paulissen, Dr. Harry Meyer, Dr. Gay Heagler, Barbara Monroe, and Joan Vallée. Their assistance was appreciated. Each draft was scrutinized by a talented friend,
Charlyne Wyche. It was due to her comments about my writing that gave me confidence to submit the many drafts of this document. Dr. Cheryl Ware, professor of languages at MSU, worked with me on the final draft of the dissertation. Without the talent of Mark Fontenot, another friend and former student, the graphics would have been much more of a chore. Words cannot express the depth of my appreciation to each of them.

It is the total experience of my doctoral pursuit which has led to its completion. However, it was the fascination of the microscope and my recognition of its importance to mankind that fueled my desire to share this information with others.
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ABSTRACT

Case studies, developed with criteria from Yin’s *Case Study Research: Design and Methods* (1994), probed single mental constructs of four introductory college biology students who were recent high school graduates. Data sources included autobiographical essays, interviews, coconstructed concept maps (Wandersee & Abrams, 1993), a videotape questionnaire, and graphics. A multisensory microscopy experiment provided the setting for the construction of shared meanings by the participants. Concept maps were used then to explore the existing cognitive framework of the participants. This research affirmed the value of supporting graphic organizers for understanding science (Good & Berger, 1998; Hyerle, 1996; Trowbridge & Wandersee, 1998).

Ausubelian cognitive learning theory (Ausubel, Novak, and Hanesian, 1978) was the theoretical foundation for this research. The heuristic device of concept mapping was used as a method to aid the student in externalizing and understanding the development and integration of relevant concepts. Ausubel (1968), Novak and Gowin (1984) recognize the positive results of knowledge construction from laboratory experiences. Expanding the student’s immediate knowledge of microscopy with instruction by the researcher helped students connect scale relationships with microscopy.

Results of this study suggest (a) that there are anticipatable and addressable gaps in their knowledge of size, scale, measurement, and micrometry that introductory college biology students bring to the science laboratory, and (b) that these gaps and misunderstandings will otherwise
impede their learning from microscopy-based laboratory experiences and frustrate their ability to measure and to grasp the relative size of microstructures and microorganisms meaningfully. Results also suggest that, the MicroMeasure™ grid system in particular may offer a new and more effective way to help students learn to interpret the magnification powers used in presenting the objects pictured in the commonplace electron micrograph images appearing so frequently on the pages of today's biology textbooks. A better introduction to and progressive articulation of the precursor concepts needed to understand microscopic images during the K-12 school experience apparently would smooth the transition from high school to college biology laboratory learning from microscopes and microscopic images.
INTRODUCTION

Value of Scale and Microscopy

Learning the procedures of measurement is an outcome of gradual conceptual development for most people. The sequence for attaining this ability is lengthy because the component skills are developed and refined throughout one's lifetime. It is dependent on experiences, needs, and interests.

Cognitive awareness of measurement entails understanding concepts of size and scale and is crucial to a student's success in college biology laboratory class where a common component of the laboratory is introductory microscopy. While it is possible that students may understand the three concepts of size, measurement, and scale without the use of the microscope, they may not fully understand microscopy without a clear knowledge of these concepts and their interrelationships.

The American Association for the Advancement of Science (AAAS) in Science for All Americans (1990) (SFAA) recognizes four common themes pervading science, mathematics, and technology, one of which is scale. It is presented as an idea that "transcend[s] disciplinary boundaries and prove[s] fruitful in explanation, in theory, in observation, and in design" (AAAS, 1990, p. 165). SFAA describes baffling phenomena in our universe which exceed our powers of intuitive comprehension and makes references to ranges of magnitude such as extremes in size, duration, and speed, and thus to scale.
The word *scale* is derived from the Latin word *scala*, which, according to Merriam-Webster (1984), means ladder or staircase. The specific connotations referenced in this dissertation are as follows:

something graduated esp. [sic] when used as a measure or rule: as a: a series of marks or points at known intervals used to measure distances (as the height of the mercury in a thermometer) b: an indication of the relationship between the distances on a map and the corresponding actual distances c: an instrument consisting of a strip (as of wood, plastic, or metal) with one or more spaces graduated and numbered on its surface for measuring or laying off distances or dimensions (p. 1047)

The importance of the knowledge of scale to students in grade levels kindergarten through twelve (K-12) is recognized by the National Research Council (NRC, 1996) in the *National Science Education Standards* as essential for "understanding that different characteristics, properties, or relationships within a system might change as its dimensions are increased or decreased" (NRC, 1996, p. 118). With descriptive language acquisition, young children typically expand their explanations by using conventional measuring devices such as rulers, balances, and thermometers.

**Education and Microscopy**

The microscope is another instrument that is useful in learning the concept of scale (AAAS, 1993). The capacity of a lens for enlarging images should be introduced early in the educative process to reinforce learning. Wonderment begins at an early age, and early magnification experiences would simplify the understanding of size, particularly that of organisms, for young people.
This heightened need for students to understand microscopy is evident from the amount of literature pertaining to the subject. *The American Biology Teacher* has few issues without one or more references to microorganisms or microstructures. Dubowsky (1996) reveals his interest in microscopy to his students by providing them with the necessary materials for the construction of a van Leeuwenhoek-like microscope. Students are able to determine the approximate magnification with the hand-held microscopes. The author and other instructors agree that this exercise provides students with a foundation which makes future microscope endeavors more appealing.

In a world being shaped by science and technology, American educators have a responsibility to provide a quality education for their students. Citizens want a society that is open, decent, and vital. Sadly, however, *deplorable* has been designated by many as the adjective describing the current condition of education in the United States.

*Project 2061* (AAAS, 1993) hopes to contribute to a national reform effort that will make considerable changes to present instruction in science. Science literacy—encompassing mathematics, technology, and the natural and social sciences—is multifaceted. Determination, resources, leadership, and time are needed to reverse the present trend. Studying the way one learns measurement and then applying this information to the concepts of scale and microscopy should have a positive impact on accomplishing the national reform effort in science education.
Gowin (1981) provides support for this possibility when he states, "A laboratory science is an appropriate place for students to undergo experiences such that regularities are tied to concepts" (p. 144). Scientists use microscopes to enhance their senses and collect data, but the value of this instrument as a tool for sustaining older students' interests in nature has been underestimated and untapped. Continuity in student enrichment may be insured with application of additional microscopy techniques thereby enhancing students' understanding of the concept of scale and possibly elevating their interests.

Case studies of four participants were used to discover how college students struggle to understand size and measurement and how they apply this knowledge to the concept of scale. Observation of these concepts, size, measurement, and scale, throughout the researcher's life has provided enthusiasm for this research. Observation of children, beginning when this researcher was a child herself and continuing to the present time, has equipped her with memorable experiences. Her bias toward microscopy began when she taught high school and recognized the increased interest of students in science as they used the microscope. Instructing biology laboratories at the freshman level of college has augmented the researcher's enthusiasm as she has continued teaching microscopy semester after semester. Perhaps her enthusiasm has something to do with discovering different organisms in each collection of pond water or watching the surprise of students as they make microdiscoveries.
In view of the preceding information, this report presents information derived from four case studies that consider the emerging consensus that there is an urgent need for consistency in the nation’s school systems. By the time of college entrance, continuity of gradual knowledge construction throughout one’s life should lead naturally to understanding of the concepts of measurement and scale. If this is presently being accomplished, evidence should emerge to support this inference. An individual’s understanding of the concepts presented in this research is an essential component of that person’s science education. By evaluating graduates of schools that use today’s science curricula, data can be collected for reconceptualizing science programs to emphasize real-world applications and connections throughout the grade levels. In this study the use of interviews, concept maps, and laboratory experiences with the microscope reveals existing and missing relevant experiences of the four participants.

What is clear, even in a superficial examination of such discussions, then, is the linking of size, measurement, and scale to microscopy. A student’s capacity to make the connections between these concepts would be dependent upon her/his real-world experiences with size, measurement, and scale. Whether students are at the elementary, middle, high school, or university level, learning these concepts and their relationships can be enhanced by visualization. Acquiring these experiences are essential as noted by Mintzes, Wandersee and Novak (1997) who “offer a view of meaning making that
stresses the significance of cognitive processes and the role of prior knowledge in the personal construction of new knowledge” (p. 53).

**Visualization**

Without the sense of sight, the phenomenon of wonderment is severely inhibited. Edward Tufte provides data graphics with quantitative information in *The Visual Display of Quantitative Information* (1983) and in a collection of treasured illustrations in *Envisioning Information* (1990). Graphics were a major source of data for this research. Interactions between the concepts of size, scale, measurement, and microscopy are dependent on visualization skills. Narrative description cannot adequately depict what the human eye can perceive and interpret. For example, through visual representation, a student should be able to grasp the size relationship between a bacterium and a protozoan.

Thompson (Bonner, 1966) spared no physics or mathematics in his 1917 volume on biostructural analysis, *On Growth and Form*. Thumbing through the pages of illustrations provides the reader with a visual presentation not only of organisms and their parts but also of phenomena such as water droplets. Cell size is discussed as the author relates the ratio of surface size to its mass. Equations explaining relationships within and between organisms abound to explain how their growth and shapes conform to laws of physics and mathematics. This abundance of equations exemplifies the importance of measurement, size, and scale to life.
Research Questions and Overview of Research

Research Questions

Metaquestions from the dissertation title were explored: (a) How do selected introductory college biology students struggle to understand scale and measurement? and (b) How can this knowledge be enhanced if studied in conjunction with microscopy?

These subquestions were addressed by multiple case studies in which participants were queried using various data collection techniques.

1. How do precollege science experiences influence the undergraduate biology student's concept of scale?
2. How do college biology students respond to three ways of representing scale on electron micrographs?
3. How are the college biology student's concepts of scale and interpretation of electron micrographs mutually influential?

Vee Diagram of Research Proposal

A Vee diagram was constructed to present the research (see Figure 1). It resolves the project efficiently and furnishes, at a glance, the lattice configuration and interaction of teaching, learning, curriculum, and governance. Gowin (Novak and Gowin, 1993) originally developed the heuristic as "a method to help students understand the structure of knowledge and the ways in which humans produce knowledge" (p. 55). Connections between the nature of knowledge and the nature of learning are made clearer by illustration with the
### Metaquestions

I. How do selected introductory college biology students struggle to gain an understanding of scale and measurement?

II. How can microscopy-based learning activities enhance students' understanding of scale and measurement?

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<th>Hypothetical Value Claims</th>
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<td>1. How do precollege science experiences influence the undergraduate biology student's concept of scale?</td>
<td>The MicroMeasure™ system is more useful and understandable than the other two systems - the traditional bar scale, and Henkograph method.</td>
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<td>Science is one way of knowing the world (Moore).</td>
<td>2. How do college biology students respond to three ways of representing scale on electron micrographs?</td>
<td>Students still relate the concept of scale to the concept of micrometry.</td>
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<td>Human knowledge is tentative and subject to change.</td>
<td>3. How are the college biology student's concepts of scale and interpretation of electron micrographs mutually influential?</td>
<td>Textbooks should consider using the MicroMeasure™ system of scaling micrographs</td>
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### Theories

- Novak’s theory of knowledge representation (Novak & Gowin, 1993).
- Gagné’s theory of educating (Gagné, 1981).
- Graphic representation theory (Tufte, 1983)

### Principles

- Cognitive structure is idiosyncratic and shows varying degrees of differentiation.
- Reception learning is as efficient as discovery learning.
- Subject matter is learned best when organized in an hierarchical manner.
- The subsumption principle refers to the addition of new material to the relationship of new material in relation to the pre-existing material in the cognitive structure.
- Meaningful learning results when a person consciously and explicitly ties new knowledge to relevant concepts or with propositions that they already possess.

### Concepts

- Human Constructivism
- Metalearning
- Hierarchical learning
- Superordinate concepts
- Resolving power
- Depth of field
- Concept map
- Metacognitive
- Subsumption principle
- MicroMeasure™ system
- Measurement
- Total magnification
- Scale
- Scale bar
- Henkograph
- Resolution
- Cytology
- Micrograph
- Micrometer
- Condenser
- Parfocal
- Magnification
- Size
- Micrometry

### Hypothetical Knowledge Claims

- Questionnaire responses will be more positive towards the MicroMeasure™ system than the alternate methods of bar scale and Henkograph.
- Students will fail to connect their previous knowledge of size, scale, and measurement impedes learning the concept of micrometry.

### Data Transformation

1. Narrative transcription and summation
2. Analysis of narrative transcripts for patterns
3. Comparison of interview participants' acquisition of relevant skills and knowledge with that of personal experience

### Records

1. Narratives on prior knowledge of size, measurement, scale and microscopy
2. Drawings and measurements with the microscope
3. Questionnaire responses on measurement
4. Answer sheet responses of micrograph knowledge with the aid of a videotape
5. Coconstructed concept maps
6. Responses to initial and final interviews

### Events

- Clinical interview responses to concept mapping and microscopy videotape
- Oral and written responses to interview questions about the participant's learning of scale
- Autobiographical responses to probes about three approaches to microscopic scaling of images

---

Figure 1. Vee diagram of research proposal
Vee heuristic. Events and objects at the point of the Vee diagram are essential to knowledge which will be constructed. Concepts on the left (thinking products) have developed over time and the concepts on the right (thinking processes) are for present inquiry—leading to new concepts and maybe even new theory.

**Definition of Terms**

The complexity of the subject matter, as indicated by the concepts listed on the Vee diagram, as well as those in the literature review, necessitates the precision of communication. Clear definitions of terms are essential to such precision, yet this precision is not facilitated, as one might assume, by comprehensive glossaries of terms in relevant literature.

The following terms and their definitions apply to this research:

1. cognition—the actions of the intellect
2. concept—a regularity in events or objects designated by some label
3. concept mapping—a schematic device for representing a set of concept meanings embedded in a framework of propositions
4. condenser—a microscope's system of lenses that focuses light on the specimen
5. cytology—the life science that deals with cells
6. depth of field—the various layers of a specimen on which a microscope is able to focus
7. Henkograph—a frame-based, micrograph-measuring system for micrographs; developed by M. C. Henk of Louisiana State University (LSU)
8. hierarchical learning—a technique whereby information is thought to be
arranged mentally in a neural network with ranked links between superordinate (broad, more inclusive) concepts and subordinate (narrow, less inclusive) concepts

9. long-term memory (LTM, secondary memory)—a component of the memory system that can hold vast amounts of information indefinitely

10. measurement—the act, or process, of determining dimensions

11. metacognitive tool—a thinking strategy that can be used to monitor one's own learning

12. micrograph—an image of a specimen depicted as if observed through a microscope lens (see Figure 2)

![Figure 2. Open stomate](Mader, Biology, 6/E, 1997, McGraw-Hill)

[Researcher's note: Magnification is 320x.]

13. MicroMeasure™ system—a scaling system employing a grid-like overlay proportionate to magnification power that is superimposed on a
micrograph; developed by J. H. Wandersee, with technical assistance by John St. Julian, both of LSU

14. micrometer—an etched-scale instrument placed under a microscope used to measure minute distances

15. micrometry—measurement with a micrometer or object of known dimensions

16. microscopy—the use of or investigation with the microscope

17. parfocal—the quality of a microscope lens system which causes it to remain virtually in-focus even when objective magnification power is changed

18. resolution—the ability to reveal detail, to distinguish two closely spaced objects as being two rather than one

19. scale—something graduated, especially when used as a measure or rule

20. scale bar—a scaling device, of unit-measure size, superimposed on a micrograph

21. short-term memory (STM, immediate memory, primary memory)—the retainer of information for about 30 seconds or less without rehearsal—often considered a component of the memory system—where information is stored and processed; associated with conscious awareness

22. size—that quality or magnitude of an object which determines how much space it occupies

23. subsumption principle—Ausubel's idea that new information often is relatable to and subsumable under more general, more inclusive concepts
24. superordinate concepts—a general, more inclusive regularity in events or objects designated by a label; a broad idea

25. total magnification—the magnification of the objective lens magnification and the ocular lens (eyepiece) are multiplied to determine the number of times that the object (being viewed) appears to be enlarged
LITERATURE REVIEW

Introduction

After examining *Benchmarks for Science Literacy* (1993), *National Science Education Standards* (1996), and several university textbooks for definitions and explanations of these concepts, the researcher found inconsistent coverage. Size was neglected altogether; there was an assumption that it was understood. Measurement was not clearly defined in any of these sources, although *National Science Education Standards* discusses measurement as a science practice (p. 118), measurement skills in grades K-4 (p. 126-127), and measurement skills in grades 5-8 (p. 149). The same source recommends association of mathematics with science (p. 214-218). The concept of scale was discussed in *National Science Education Standards* and *Benchmarks* but was never specifically defined. In discussions of these concepts, there is reference to even more complex relationships such as ratio and proportion.

The simplest concept, size, can be understood without reference to either measurement or scale. Size is recognized visually prior to their introduction to measurement. A related term, or concept, that of magnification, appears quite early. Recommendations in *Benchmarks* (1993) are for K-2 students to use magnifiers (hand lenses) for enlarging objects not visible to the naked eye. Students in grades 3-5 should acquire experience using dissection scopes or low power on microscopes to observe microscopic organisms.
Benchmarks recommends that students in grades 6-8 “use photomicrographs to extend their observations of cells, gradually concentrating on cells that make up internal body structures” (p. 112).

In kindergarten measurement is introduced with paper clips or other manipulatives; in elementary school curricula students first learn to determine size using a ruler with the English scale and later the metric scale. In high school biology, students measure temperature, volume, mass, and length; in geometry, they learn to measure angles and area; in chemistry, measurements of volume, mass, and temperature are covered; and in physics, more complex formulas for determining range, velocity, and acceleration appear.

Theoretical Base for Research

Conceptual Learning and Memory

Relationships between meaningful learning, cognitive structure, and conceptual change continue to be a significant focus of research in science education. For over two decades, research in the cognitive realm of science learning has provided evidence that successful science learners and scientists develop elaborate, strongly hierarchical, well-differentiated, and highly integrated frameworks of related concepts as they construct meanings (Wandersee, Mintzes, and Novak, 1994). The ability to reason well in the natural sciences is constrained primarily by the structure of domain-specific knowledge in the discipline.
Novak (1977) explains one theory of school learning by comparing works of philosophers Toulmin and Kuhn and by discussing at length the cognitive learning theory of educational psychologist David Ausubel. By admission, Novak argues for the substitution of Ausubel's theory for Piaget's:

Ausubel's meaningful learning...is idiosyncratic, and the development of cognitive structures that will allow new experience to be incorporated meaningfully into an individual's structure will be dependent upon the past sequences of his experiences and on the kind of cultural heritage in which he is embedded. (p. 124)

Novak justifies this statement on "both empirical studies and on philosophical grounds" (p. 124).

Ausubel's theory of meaningful learning (Ausubel, 1963) focuses on concept and propositional learning as the basis for individuals to construct their own idiosyncratic meanings. A key factor in this theory is that meaningful learning depends on the framework of relevant concepts or propositions that an individual already possesses. Although his cognitive assimilation theory appeared in 1963, it had little impact until after his 1968 *Educational Psychology: A Cognitive View* (Mintzes, Wandersee, and Novak, 1999). Using strategies ranging from reception learning, where information is provided for the learner, to autonomous discovery learning, where the learner chooses her/his own information to be learned, the learner constructs new knowledge by observing "events or objects through the concepts we already possess" (Novak and Gowin, 1993).

Ausubel asserted that "The single most important factor influencing learning is what the learner already knows. Ascertain this and teach him
accordingly” (cited in Mintzes, Wandersee and Novak, 1999). Clearly, then, a
teacher (or researcher) must ascertain a student’s prior knowledge of key
concepts, devising varied and appropriate methods in order to do so.

These concepts may be stored in memory by different methods. Two
coding systems for memory have been suggested by Allan Paivio (1986) in his
dual coding theory of mental representations. He proposes that incoming
linguistic information is represented in a verbal coding system, whereas
nonverbal pictures, sensations, and sounds are represented in a functionally
separate image-coding system. Paivio claims that verbal memory traces are
weaker than nonverbal traces and, therefore, his theory predicts that students
will recall concrete, highly image-based material more easily than abstract,
verbal material. Dual coded material should be the more memorable. This
theory also supports using hands-on materials for enhancing learning.

Whereas learning involves acquiring new knowledge, attitudes, and skills
or information, memory retains that material. The more exposure one has to
certain concepts, the more readily the individual can retrieve and expand those
concepts. Benchmarks for Science Literacy (1993) proposes that it is “memory
of their past experiences that humans use to make judgments about new
situations” (p. 140). If an experience has produced pleasant consequences for
a person, the person is more likely to want to repeat it. Benchmarks also
asserts that learning means using what one knows to make sense from new
experiences or information instead of just storing concepts in the head.
Memory research has come a long way since Aristotle's assumption that the mind is centered in the heart instead of the head. Gowin (1981) has synthesized ideas from philosophy and science by integrating his experiences into a more complex pattern. In *Educating* he expresses the idea that understanding one's personal education is a "deliberate connection making between thinking and feeling which leads to intentional human acting" (pp. 48-49).

**Key Concepts**

**Size**

Authors (Amato, 2000; Gould, 1977; McGowan, 1994; Strauss, 1995; Thompson, 1917) are aware of complexities associated with understanding size. Using mathematics, physics, geometry, and evolution to explain this phenomenon only complicates this concept for the non-scientist. This complexity further underscores the need for gradual introduction to the various aspects of size determination.

**Measurement**

Wilson (1995) writes that measurement and computation link ancient astronomy and modern science. Instruments of ancient and medieval times were not so much used for their purpose during these early periods as they were used for symbols that certain people held possession of particular knowledge. Design or features of instruments were of more significance than the actual use of the instrument. With the introduction of technology, skepticism...
has come from the public sector. Cultures were hesitant to accept information, not just from the scientific community in general, but from the results of information formulated by instruments. Public acceptance of scientific information as factual knowledge continues to be problematic, even in modern times.

Units of measurement are essential to science. Klein (1974), in The World of Measurements, summarized that “Measurement is a massive, many-sided activity in all branches of production of the necessities, conveniences and luxuries of life” (p. 24). These units of measurement include length, area, volume, time duration, and weight. The science of measurement is known as metrology. The author wrote this book, not only for scientists, but also for nonscientists so that they would realize how many of their daily activities involved measurement.

Teachers of elementary children continue to find innovative ways to introduce young children to the concept of measurement. Lubinski and Thiessen (1996) used the 1990 children’s book by Myller, How Big Is a Foot?, as an impetus for creating an entire unit about linear measurement. Several tasks with constructed paper footprints were completed before students used rulers for measuring. Lubinski found that students’ skills had increased considerably when compared to previous years when the ruler and measuring objects had been used to introduce linear measurement.

Units, other than those of the metric system, which continue to be used in the United States today are essentially the same units introduced by the
English colonists. Cultures contributing these measures included the Babylonians, Egyptians, Romans, Anglo-Saxons, and Norman French. To recall a few primitive measurements, some past measurements will be mentioned. Some important units of length have no known origin and for this reason they have come to be designated as arbitrary (Klein, 1974).

Measuring preceded weighing because it was easier to accomplish (Bendick, 1947). Methods of measuring were very simple initially, with man using body parts for measures. This sufficed until civilization became more complex. The amount a man could carry or hold was the initial method of determining weight. To develop the idea that weight was different from the size or material under consideration took more time for earlier civilizations to grasp.

There has been no simple adoption of standards for establishing universal measurement units. Adopted standards have, at times, been changed, corrupted, or destroyed. Rulers were responsible for issuing decrees to achieve unity and order in measurement standards. When the kings sent inspectors with their set standards, the inspectors would find trades people continuing to use whatever standards of units they always used. Inconsistency in the incorporation of the standards resulted in distrust by the people.

No record to establish a permanent standard was attempted until the building of the great Khufu Pyramid in Egypt about 2900 B.C. (History of Measurement, 2000). The length used was the measurement of the Pharaoh's forearm and hand. The standard was cast in black granite and was called the Royal Egyptian Cubit. Precision of this measurement is realized by the
exactness in the construction of the pyramid. No side of the pyramid’s base deviated from the mean side length of 9,000 inches by more than 1/20 of 1%.

From 4000 B.C. to 1100 B.C., Egyptians measured with a knotted cord called a kite (Miyamoto, 1974). From 1700 B.C. to 1525 B.C. Babylonians measured with the cubit, originally the distance from a man’s elbow to the tip of the longest finger of the extended hand. Eight different measures have been identified for the cubit (Klein, 1974). In 500 B.C. Phoenicians measured in finger widths called zebos, and a standard cloth measure was 50 zebos. A fathom, an armstretch, was 100 zebos also known as a nent. The Greeks used the cloth measure but reduced it by 5 zebos which made it 45 zebos; this reduction made the cloth measure comparable to 3 pous or 3 foot lengths. The Greek fathom was 90 zebos or 6 pous long. These regional adjustments continued to be common for centuries.

Travel by the Romans between 300 B.C. and 300 A.D. brought about the development of linear measurements of the foot, pace, and furlong (Klein, 1974). A foot was 12 finger widths; a pace (double step) was 5 feet; and, a furlong was one-eighth of a mile. The mile was 1,000 paces. The words “inch” and “ounce” are each derived from the Latin word, *uncia*. The word *uncia* represented the twelve divisions of the Roman word, *pes*, or foot. Indications are that Romans had an established standard measurement system which enabled them to construct complex routes of aqueducts which had constant incline from distant mountain lakes to coastal cities. Only precise measuring instruments related to a set of established standards could have accomplished
this feat (History of Measurement, 2000). Metrological measurements introduced by the Romans continued to influence Britain and Europe, even after the fall of the Roman Empire.

The Dark Ages, a period from 476 A.D. to the modern era (c. 1450), brought retrogression to technology in many areas and, in particular, squelched attempts by monarchs in establishing standards. From 900 A.D. until 1100 A.D., the Anglo-Saxons used various lengths of cloth to measure the length of a yard. The sash worn around the waist of an individual was supposed to measure the yard. The word "yard" was derived from the Saxon word gird, which was the circumference of a person's waist (Klein, 1974). In the tenth century King Edgar standardized the measure by letting the distance from his nose to the end of the finger of his extended arm represent the yard. He supposedly kept a yardstick at Winchester and considered it an official standard of measurement ("National Physical Laboratory," 2000). The inch was the length of three barley corns. However, complaints of size variation in the three round, dry barley corns representative of this one-inch measure were frequently expressed (History of Measurement, 2000). Other measures used by the Anglo-Saxons included the acre, the amount of land plowed daily by a pair of oxen, and the hide, the amount of land plowed yearly by a pair of oxen (Miyamoto, 1974).

Even when King John signed the Magna Carta in 1215, land barons recognized the need for one metrological system (Klein, 1974). King John had iron bars representing uniform units for merchants to employ as their standards.
Unfortunately, these measures, according to Klein (1974), were "contradictory, complex and racy, replete with deviations, devices and dodges, most of them tending to enrich cheating merchants, local officers and money-hungry monarchs at the expense of those more honest but less influential" (p. 29). The measures had no subdivisions at this time, which compounded problems when fractions of measurement were needed. Later in 1490, reform efforts introducing a crudely-divided octagonal yard bar were attempted by Henry VII. Following his efforts one hundred years later, Queen Elizabeth replaced the yard bar with a brass rod about one-half inch square. She accomplished some standardization of measures of capacity, width, and length. Technology was attempting to revive from the Dark Ages.

In the seventeenth century, scientists and technologists began collaborating to produce better measuring tools. No national or international system provided uniformity of measurement. Instrument makers were aware of variation in measurement caused by temperature and pressure, and therefore they produced measuring instruments better than the existing national standards (Klein, 1974). Universities were established and the past achievements of the Greeks were once again realized. Still, because there was no national or international standard of measurement, experimenters could not reproduce the works of their colleagues.

A Scottish inventor and instrument maker, James Watt, suggested that all scientists develop a new system of measurement (Klein, 1974). Watt was active in the Royal Society in England and was acquainted with the scientists of
France. The French were interested in this endeavor because they had never incorporated a national system in their country. After dispelling the idea of a unit of length being derived from the swing of a pendulum, French scientists decided to derive the unit of length from a dimension of the earth. The unit agreed upon was that of the meter. "Meter" is from the Greek word *metron*, which means measure. Because this word was reasonably known as being accurate, the meter was adopted quickly. Unfortunately, this adoption had occurred during the French Revolution, and like so many other attempts of establishing some uniformity in measurement unit, it too failed. In 1800 Europe had not been successful in implementing measurement technology.

Following the War of Independence, the United States Congress recognized the advantage of uniform standards for weights and measures. However, there was no more success in this endeavor than there had been in Europe. Each state had its own system of measurement. Ferdinand R. Hassler, a mathematics instructor at West Point, was appointed to conduct a survey of the coast in 1807 (History of Measurement, 2000). After observing the Navy Department and Treasury Department disagree about the measurement standards to use for the Coast Survey, Hassler chose a bar made by an English instrument maker, Troughton, to be the standard unit of length for the yard. Hassler had intended to compare it to the yard measurement of Parliament, the ultimate authority. In 1834 the yard measure of the English Parliament was destroyed by fire. Upon restoration and comparison of the Bronze No. 11 yard of Parliament, Hassler's Troughton scale was discarded.
because it was 0.00087 of an inch shorter than that of the English scale. Bronze No. 11 became the accepted standard of length in the United States.

An International Conference on Weights and Measures of seventeen nations, including the United States, was held in 1875 (History of Measurement, 2000). Europe was slowly adopting the metric system. The same year the Treaty of the Meter Committee was organized to construct permanent standards. There was also a provision in the treaty for the establishment of an International Bureau of Weights and Measures to be established on neutral ground in Sèvres, France. When the prototype meter bar and kilogram constructions were completed, the two specimens were placed in an underground vault in Sèvres. They remained intact throughout both world wars.

Other prototypes were distributed to the treaty nations. In 1893 Meter Bar No. 27 and Kilogram No. 20 were accepted as our fundamental national standards in a ceremony conducted in the office of President Benjamin Harrison (History of Measurement, 2000). The United States failed to establish national laboratories to regulate measurements and standards and also to establish uniformity between manufacturers and industries. Non-uniformity was the norm, not the exception. The Office of Weights and Measures found the task of getting manufacturers and industries to agree unsurmountable.

The National Bureau of Standards (now called the National Institute of Standards and Technology or N. I. S. T.) was established in 1901 by Congress (History of Measurement, 2000); its responsibility is to maintain the existing standards and to create and regulate any new standards. Presently, there are
over seven hundred different standards. This bureau also conducts research in fields related to metrology.

The Système International des Unités (usually designated SI) is called the International System of Units by the English-speaking people. This name was assigned to the metric system by the General Conference on Weights and Measures in Paris on October 1960. An international agreement, the Treaty of the Meter, originally consisting of 36 nations approved the system for science and technology. Its acceptance is worldwide with few exceptions (Klein, 1974). In 1964 the British chose to accept the metric system over a ten-year span. The United States Congress passed the Metric Study Bill in 1968. During the next ten years, the United States was also supposed to adopt the metric system as the primary system of measurement; this feat has not been accomplished. Improvements in and additions to SI are made periodically by the General Conference (Brief History of Measurement Systems, 1991).

Lord Kelvin designated the concept of measurement as something necessary for understanding the natural world (Asimov, 1988). Strauss (1995) had enough curiosity about measurement to devote an entire book, The Sizesaurus, to the subject. The author makes every attempt in his preface to allay readers' fears about the metric system. He says clearly that “metric is king” (p. ix).

Scale

Measurement is essential to all fields of science. Observations of researchers are translated into numbers through the process of measurement.
According to Steven's Scales of Measurement (1951), the most widely applied taxonomy of measurement procedures, four scales of measurement are available for analyzing data. These scales involve assigning numerical figures to differentiate items. Certain scales of measurement are applied to certain operations. After variables are determined, the researcher decides the best way to express them in numerical form.

Nominal scale data is incorporated when examining a particular value or when counting the number of occurrences of each value (Ary, Jacobs, & Razavieh, 1990). This type was the first kind applied, and it results in the assignment of categories. Gender, eye color, sex, political party assignment, and other phenomena are examples of nominal scale variables. It is recognition of whether or not an object or individual belongs in a specific category.

Numbers may be used with nominal scale data but only to identify categories. Numbers are arbitrarily attached to categories and serve as labels. If labels of categories are changed, no empirical relationship is affected.

The ordinal scale data would be applied when determining if values are greater than or less than and would involve rank-ordering. An example would be some comparison that could not be quantified, such as political party position with reference to the right or left wing. Ordinal scales have continuous variables derived from an infinite number of values between two points (Schumacher & McMillan, 1993). Data are difficult to understand and difficult to make sense of. Scales involving a ranking are ordinal such as Likert scales which rank degrees of satisfaction. Hotel or restaurant ratings would also be
considered ordinal data. Group data are organized to interpret results of information obtained from ordinal scales.

Interval scales have units with equal distributions so that observations are comparable. The primary difference between ordinal and interval scales is that the interval scale has equal intervals between each number. Constant units of measurement are provided. Meaning is attributed both to the order and distance relationships among the numbers (Ary et al., 1990). There is no true zero point on an interval scale. Instead, the zero point is designated by convention. Fahrenheit and Centigrade temperature and standardized achievement test scores are examples of interval scales.

Temperatures are important to precision measurements because they can affect the length of structures, particularly when considering a factor such as moisture. Thermometry, the measurement of temperature, has played a vital role in the success of science.

In 1714 the German scientist Gabriel Fahrenheit expanded the previous efforts of thermometrists when he purified mercury and produced a mercury-in-glass thermometer superior to any produced prior to his time. About 1726 a French natural philosopher, René Réaumur, developed another thermometer using measurements based on alcohol and water mixtures (Klein, 1974). This scale was used more with the mercury thermometers than with alcohol thermometers to determine basic measurements of thermal effects. Although the Réaumur temperature scale was used extensively in France and Germany for generations, this nonthermodynamic scale is now obsolete (Klein, 1974).
Celsius, a Swedish astronomer, recognized the need for a more efficient thermometer to record meteorological data. His first thermometer, developed in 1741, is the most frequently used instrument for measuring temperature. The present Celsius instrument owes its evolution to at least three other men, Christin, Strömer, and Ekström (Klein, 1974). The Celsius name prevailed for more than one reason. Berzelius, a Swedish chemist, attributed Celsius as the maker of the thermometer. Also, Celsius deserved lasting recognition because of his work to diminish theologic belief which at that time was stifling scientific progress.

The fourth and most refined type of measurement is represented by the ratio scale (Schumacher & McMillan, 1993). Ratio numbers include distances attained, strength indicating amounts of weight lifted, or times needed to perform certain distance relays. Meaningful comparisons are possible using ratios since numbers from both ordinal and interval scales can be compared by expressing them as part of or so many times some other number. Ratio data are also scientific measurement units associated with microscopy. The ratio scale provides a true zero point with equal intervals, and with this scale observations can be compared as ratios or percentages, i.e. Kelvin temperature. Statistical procedures are appropriate with a ratio scale (Ary et al., 1990), and either interval or ratio scales are used to determine statistical procedures of mean and variance.

Geometric figures in mathematics textbooks often incorporate the use of ratio and proportion in scale drawings. McKillip and Kay (1985) present atypical
problems involving measurement for junior high mathematics and secondary
general mathematics courses. This variety of exercises in space and scale
models is not found in textbooks. Besides solving the mathematical
computations of these problems with metric and/or customary units, students
have the additional experience of researching information in the library.
Students are provided a practical application to their everyday life when using
customary units to solve "scaled speed" (p. 544) problems.

Karplus, Pulos, and Stage (1983) conducted a qualitative study with
11-year-olds and 13-year-olds dealing with features of proportional reasoning
on dimensional intensive variables. Concepts of ratio and proportion were
separated by ratios of denotate numbers and those of rates. The former are
speed, shape, or a characteristic which would result in a ratio relationship; the
latter are dimensionless and would refer to sizes of photographs, revolutions of
gears, or ingredients in a recipe.

Proportional reasoning refers to intensive and extensive variables.
Intensive variables are speed, shape, or some characteristic defining a
constant ratio relationship (Karplus et al., 1983). Extensive variables are length,
time, weight, or other quantitative description of an object or event. Students in
that study were presented four proportional problems, two pertained to chewing
gum purchases and two involved running laps varying in numerical and
referential content. Although age appeared to be insignificant, the relative
frequency with which problem solving was approached was greatly affected by
context, numerical content, and the immediately preceding task. Errors in
computation which occurred in problems of this study may account for miscalculations performed by students when attempting to calculate proportions of magnified size to actual size.

Proportional reasoning is important in everyday situations, in the sciences, and in the educational system. Tourniaire and Pulos (1985) found research on the subject to be lacking in cohesiveness and difficult to apply to mathematics education. Their research focused on methods to alleviate these shortcomings. With certain types of problems presented to determine a student's ability to answer a comparison, the student need only choose the correct one. Overestimating a student's ability may result from this answer-only mode, since it can be generated from non-proportional reasoning. Four tasks are used with the different methods of task delivery. The categories of consideration are physical tasks, rate problems, mixture problems, and probability tasks.

Two kinds of ratios can be compared when calculating proportions. A scalar method, or internal ratio, is used for comparing ratios of quantities of the same nature, such as two amounts of money. A functional method, or external ratio, is applied if the quantities are of different natures. The scalar method was used by the ancient Greeks (Tourniaire & Pulos, 1985). Functional relationships are more recent and require a more abstract approach. It is the context of the problem which determines the choice of the scalar or functional strategy.

Evaluating the problem solving approach used by students in chemistry classes needs to be reassessed, according to Wheeler and Kass (1977). They
report students lack the ability to transfer their general proportional reasoning to proportional reasoning needed in chemistry classes. Many students were found to solve problems using additive techniques rather than proportional reasoning techniques. Wheeler and Kass suggested devising some test items in a qualitative fashion to help students understand concepts more thoroughly.

Tourniaire and Pulos (1985) conclude that proportional reasoning is a multi-faceted activity and that it could probably not be taught in a linear sequence. Their review of the research found that proportional reasoning is much more difficult than thought. Lamon (1999) reports that more than half the adult population cannot reason proportionately. Both age and experience contribute to success in solving complex problems. In conclusion, Tourniaire and Pulos (1985) suggest that “knowledge of cognitive correlates should guide both the timing and the nature of the introduction of proportional concepts” (p. 200).

Gabel and Bunce (1994) found that the ability of learners to solve problems, particularly in proportional reasoning, is dependent on the developmental level of the learner. Specific areas of aptitude include reasoning in spatial ability, memory capacity, prior knowledge, attitude toward the learning environment, and personality orientation. Gabel and Bunce researched problem solving in chemistry because the focus of curriculum projects is shifting to a more societal focus.

In an attempt to address some of the preceding problems associated with proportional reasoning, Lamon (1999) has published Teaching Fractions
Lamon (1999) does not offer a concise definition of proportional reasoning but states that its meaning “draws on a huge web of knowledge” (p. 5). Proportional reasoning is acquired with time and may be facilitated by interactions between many aspects of situations. Understanding concepts associated with proportion does not develop in isolation. Lamon identifies six areas which promote powerful ways of thinking: (a) relative thinking, (b) unitizing, (c) partitioning, (d) ratio sense, (e) rational numbers, and (f) quantitative reasoning. Proportional reasoning requires special knowledge of concepts, of ways of thinking, and of acting. When the preceding are linked with appropriate contexts, “researchers use the term multiplicative conceptual field” (p. 4). This distinguishes from the less complex additive reasoning.

Long-term studies cited by Lamon (1999) demonstrate that instruction can be improved if implemented over a period of at least three years. Studies of students' reasoning abilities produced positive results in proportional reasoning. Traditional algorithms for operating with fractions and ratios were not taught to students participating in this study. Camacho and Good (1989) found that
novices lack understanding in developing or modifying mathematical relationships. Instead, novices try to use formulae or algorithms to solve problems. Developing critical thinking skills of proportional reasoning in middle school as suggested by Lamon (1999) and continuing to use these skills in subsequent courses may promote more success with problem solving (Raven, 1987).

Research in the area of proportional reasoning is important because of its relationship to critical areas of mathematics and the sciences, including algebra, geometry, chemistry, physics, biology, and geography. Additionally, proportion is useful in everyday contexts, such as recipe conversions, gas consumption, map reading, scale drawings, steepness, fluid concentrations, speed, reducing and enlarging, comparison shopping, and monetary conversions (Lamon, 1999).

When coping with interactions of the world, both scalar and vector variables are indispensable for measurements. With scalar, or nonvector variables, direction is disregarded. Examples of scalar variables include length squared, energy, and power. Vector variables always include magnitude and direction as components with measures such as velocity, acceleration, force, or momentum (Klein, 1974).

Another experience with scale is demonstrated by the logarithmic Richter scale which is used to measure earthquake magnitudes. It is a nonintuitive relationship to many students. If three points are equidistant on a graph, one would say intuitively that the distance to the last point is twice as far as the
distance from the second. This would derive from having had experience with an arithmetic scale, such as measurement with a ruler. On the Richter scale of earthquake magnitude, however, each +1 change represents a 10-fold increase in seismic wave amplitude. Therefore, when comparing 2 earthquakes with amplitudes of 5 and 7, for example, the seismic wave amplitude of the latter is 100 times greater than that of the first. Intuitively, many students initially say that the seismic wave amplitude of a magnitude 7 earthquake is 20 times greater than that of the 5 magnitude earthquake (R. C. Rettke, personal communication, July 17, 2000).

Measurement, size, and scale are not separated from daily life as the preceding discourse demonstrated. Toumasis (1993), when instructing his students about logarithms, promotes introducing historical material in high school mathematics. Freudenthal (1981) recognized this premise, also, and argues for integration of the history of science with subject matter.

**Microscopy**

The value of using a microscope to facilitate the learning of micrometry and measurement may seem unclear to a person unfamiliar with the history and technology of this instrument, but a simple library search into any scientific field would establish it. Microscopy pervades every science and supplies information which leads to invaluable discoveries. An understanding of the concepts of size measurement, and scale is necessary before anyone can utilize the microscope to its full potential.
Using dust as the boundary between the visible and invisible, Amato (2000) introduces the microscope as one of the measuring devices which "opened the door to the realm of the truly small and invisible" (p. 59). To trace the early importance of the microscope, Amato describes and outlines significant discoveries which were attributed to it. The impact of microscopy to medical history is presented with examples of life-saving breakthroughs.

Amato (2000) writes of medieval thoughts about the "inferior microcosm" in comparison to the "superior macrocosm" (p. 41). Metaphor and analogy rather than observation and enumeration are methods for explaining the minute. Even sensations of sight, sound, taste, and smell are attributed to the emission of particles. The lack of technology and infatuation with visible elements occupy the curiosity of the philosophers, scholastic thinkers, and theologians.

Wandersee, a professor of biology education at LSU, has praised the genius of Leeuwenhoek for many years. In the preface of Bioinstrumentation (1996), Wandersee credits Leeuwenhoek for building "247 high quality, single-lens microscopes—grinding 419 lenses, some as small as a pinhead" (p. vii). The microscopic techniques that the Dutch linen draper developed were used for almost a century. How did this early microscope contribute to current research technology? Wandersee answers, "His [Leeuwenhoek's] technological improvements illustrate this simple fact: no amount of learning can overcome the limits of our sense organs" (p. vii).
To describe the microscopic structures, references about size, measurement, and scale had to be established. Standardized scales of units for measurement were nonexistent during the seventeenth century. This absence precipitated the necessity for microscopists to use common objects for size comparison of structures viewed under the lenses of microscopes. Few researchers discount the contributions of Antony van Leeuwenhoek, a seventeenth-century biologist and master microscopist who recognized the potential of his homemade microscopes. Wandersee (1986) and Dobell (1960) describe Leeuwenhoek's techniques for measuring with comparative and usually precise "biological 'metersticks,'" such as sand grains, human red blood cells, vinegar eels, millet seeds, and the eye of a louse. Leeuwenhoek compared his "little animalcules" to a sand grain in a letter to Robert Hooke. This estimation used by Leeuwenhoek was illustrated by Wandersee (see Figure 3).

The standard inch, as defined in Holland during Leeuwenhoek's time, was equal to 30 coarse or 100 fine grains of sand placed end to end. Dobell (1960) concurs that Leeuwenhoek's measurements, even though crude, were remarkably accurate. Leeuwenhoek tried to use the "inch," as it was then defined in Holland, in a letter that he wrote in 1679 to Christiaan Huygens. For this measurement he used a hair from his wig to determine the absolute diameter, concluding that 600 hairbreadths represented the length of one inch. This method of using some object to represent a measurement is the "transfer scale" used today, as approximations are sometimes prone to error.
Robert Hooke, in *Micrographia*, 1665, actually used the scale bar as one of his illustrations, and he placed the drawing of a length bar in one of his illustrations. At other times he counted and estimated the number and size of objects. Other references relate his counting and estimating numbers and sizes of objects. Only a competent microscopist could have made these calculations, according to Bradbury (1991).

In 1718 Jurin employed a comparison technique for blood cell measurement. He wrapped a long, thin hair around a needle, making sure with every turn the hair was in contact with the previous turn of hair. Jurin used the number of hair turns as another measurement that came to be commonly used during this time period. He then cut the hair into segments and added the
segments to a blood sample which was on a plane (flat surface). His estimates were extremely accurate when compared with the modern unit of measurement, which is about 7.8 micrometers (Bradbury, 1991).

Micrometers were mentioned as early as 1716, when Hertel described a screw micrometer in the body tube of his microscope and a net micrometer on the stage of his microscope. Benjamin Martin and George Adams accessorized their microscopes with screw micrometers about 1738. In 1747 John Cuff used silver wire in the construction of his micrometer. Various materials in addition to silver formed the lattices of early micrometers. Human hair and threads of the finest black silk, for example, were also used as measuring devices (Bradbury, 1991).

The 19th century was a time of advancement for microscopy. Screw micrometers similar to the filar micrometers developed in the late 19th century are still in use today. Refinement of optical components, as well as other accessories, led to improvement and accuracy in microscopic research. Many different patterns of graticules were devised, but not until the second half of the twentieth century were electronic measurement and basic changes in measurement technique introduced (Bradbury, 1991).

Mason (1983) summarized the various methods of determining the measurements of length for objects viewed with the microscope: (a) visual estimation of size, based on a knowledge of the magnifying power; (b) measurements obtained by means of a drawing camera in combination with a stage micrometer; (c) comparison of the object and a micrometer scale; (d) use
of micrometer eyepiece containing a fixed or moveable graticule; (e) projection
scale of known size into the field of view; (f) measurements on projected real
images; and (g) vertical distance measurement using a calibrated fine focus
knob. Calculations of measurement by the preceding methods may contain
errors. Commercially available equipment presently provides microscopists with
sophisticated technology for attachment to standard microscopes. Electronic
and mechanical instrumentation for measuring microscopic images has
removed a portion the stress associated with precision measurements. Visual
fatigue has been reduced and speed in calculations has been increased with
the technological advancements.

Units of measure differed from country to country when microscopists
first applied measurement to their work. When the inch was referenced by
Hooke, it would often have to be subdivided. A line, equivalent to one-half inch,
was often used by Europeans, while measurements were quoted in fractions of

A new system introduced by France in 1800 ushered in the meter as the
basic unit of length. This step was the beginning of the metric system. The rest
of Europe eventually adopted the system, with the micromillimeter or micron as
the working unit. The tenth General Conference of Weights and Measures of
1954 revised the metric system. The Système International d'Unités has
replaced the term micron with micrometer (Bradbury, 1991).

In 1973 Piller (Bradbury, 1991) categorized two different types of
measurement that are possible with microscopes. Measurements of
dimensions (e.g., length, breadth) and calculation of the area of objects, together with a count of features in the field of view, are considered geometrical measurements. Optical features of reflectance or transmittance of an object, its refractive index, and properties related to polarized light are optical measurements. College undergraduates and younger students are usually concerned only with the geometrical category. Thus micrometry provides a more meaningful experience for students because this type of exercise combines the two types of measurement. The concept of scale is actually an outcome of this synthesis.

Measurement with microscopes is more precise when the optical systems are as free of aberrations as possible. Many microscopists have examined instruments from the 18th and 19th centuries to assess their accuracy. David Jones of Aberdeen, Scotland, a Fellow of the Royal Microscopical Society, reappraised microscopes which had been designed in the eighteenth and nineteenth century. Interest in studying the microscopical images produced by the older lens systems was influenced by Jones’s research, which involved the use of optical and electron microscopes. Spherical and chromatic aberrations are commonly a problem of images produced by early microscopes, but correction of these defects is possible with a combination of lenses made from glass having different dispersion qualities and also with the use of single lenses with biconvex surfaces (Bradbury, 1991).

In a recent article, Brian Ford (1998) related how he used one of the more than 500 microscopes made by Leeuwenhoek to conduct some of
Leeuwenhoek's original experiments. His findings support claims made by Leeuwenhoek that his lenses were able to resolve the structure of red blood cells. Carmichael of the Mayo Clinic related how much he appreciated details of micrographs by microscopist Ford in *Microscopy Today* (1998, June/July). Ford had examined microscopes used by Robert Brown, the discoverer of the nucleus. Ford was able to view not only the nuclei of cells but also smaller organelles such as mitochondria. Detractors have refuted the claims of early microscopists but investigations by scientists like Ford attest to their skills.

Jones also assessed the Cuff-type lacquered, brass monocular and the Victorian microscopes by using current chemically preserved and stained biological specimens. He found that the lenses produced images with spherical and chromatic aberrations. Dolland and Lister corrected this problem later, in 1830 (Jones, March 1998).

Resolution, the ability to distinguish two distinct points from the initial blur, is the best measure of a microscope's capacity. Leeuwenhoek's microscope could resolve to 1.25 micrometers. Single lensed microscopes like Leeuwenhoek's are not so subject to optical aberrations as the early compound microscopes were (Wilson, 1995).

The concept of scale continues to be a difficult concept for students. In *American Biology Teacher* (Rice, 1999), an outdoor activity involving the concept of scale for high school or introductory college classes is presented. The heights and trunk diameters of trees are measured to test an hypothesis about the strength of tree trunks. Results gleaned from the procedure provide
information, not only about biological principles of proportion, but about the interaction of math and science.

In the past scales of measure varied between locations. Distances were estimated, lengths were averaged by measuring quantities of loads, and precious things received the most precise measures. Prior to the Middle Ages, carob beans were used to measure diamond weight. Grain sufficed as a denomination of Sicilian currency and as the definition of an inch (Amato, 2000).

McGowan (1994) is fully cognizant of the central importance of size and scale to the survival of living organisms. Scale differences of various life forms are approached by examining their physical properties according to where they reside—land, water, and air. Throughout his book Diatoms to Dinosaurs: The Size and Scale of Living Things, McGowan relies on observation, comparison, and mathematical relationships to present size-related phenomena. The author proudly asserts that his information "not only illustrates how scale differences affect all aspects of life, but also how these underlying principles are seldom acknowledged" (p. 244).

Darwin's observation skills were referred to several times and were referenced in McGowan's data (1994). Advantages of beak size in birds to insure natural selection were discussed. Size-related differences in bird flight patterns were studied in depth. McGowan mentioned Darwin's notes about the soaring patterns of condors to introduce his chapter on flight.
Measurement continues to baffle college students. After having taught microbiology more than 20 years, Foos (1996) devised a simple visual aid to help his students understand the concept of microscope calibration. By comparing markings on an uncalibrated ruler to known units of a meter stick, students are able to “make inferences about the relationship of calibrated and uncalibrated micrometers” (p. 162). The simple analogy allows a more rapid assimilation of the latter relationship.

Strauss (1955) credits Lord Kelvin with recognizing that

. . . if you can measure that of which you speak, and can express it by a number, you know something of your subject; but if you cannot measure it, your knowledge is meager and unsatisfactory. (p. 3)

The author realized the complexity of measurement and devoted an entire book to the subject, The Sizesaurus. Comparisons of sizes are examined from the minute to the gigantic. Strauss attempts to intersperse humor, but to any reader the gravity of the subject is obvious.

The importance of understanding measurement cannot be underestimated. The Toronto Star (October 14, 1999) reported the recent blunder of a company submitting acceleration data for the National Aeronautic and Space Association’s (NASA’s) Mars mission which used pounds of force instead of metric newtons in calculating acceleration. The cost to the United States was $125 million. Does not this example clearly indicate the extensive impact of teaching measurement in our schools?

Both systems of measurement have been taught in our schools for many years. Europeans have been converting from English and other units to metric
units since the 1970's. In January British wholesalers made their transition to metric measurements according to *The Gazette of Montreal* (January 5, 2000). Young people who were introduced to the metric system in school report no problems with the conversion, but the older generation is having difficulties in adjusting.

The description of any object includes its measurement as an essential part. Including features such as shape, texture, and color can add some clarity; but these terms do not designate details that are necessary for establishing specificity. Measurement is the objective means for description.

**Previous Findings**

A review of the literature which examines consistency of micrometry with microscope studies reveals few experiments with measurement and/or microscopy in courses like introductory biology. Measurement in mathematics rarely deals with lengths of less than a millimeter, and a microscope has not been the tool of choice in mathematics for practicing these measurements. In biology, students make microscopic examinations; but they have little or no exposure to micrometry. The most common computation with the microscope is calculating total magnification, and student exposure to the metric system is usually accomplished with the completion of one exercise.

Several studies (Clements, 1999; Heibert, 1981; Kamii & Clark, 1997) confirm the importance of learning the concept of linear measurement. Each article describing those studies references logical reasoning abilities identified

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by Piaget. In each one application of the concept is stressed as an integral strategy for improving students' reasoning abilities.

For the last 20 years, researchers have shown significant interest in demonstrating the role of illustrations in improving comprehension of textbook information. Blystone and Dettling (1990) provide multiple references for science teachers who are interested in the impact of textbook illustrations on learning science. Mayer, Bove, Bryman, Mars, and Tapangco (1996) found that college students at a research laboratory in Santa Barbara performed cognitive processes necessary for meaningful learning more efficiently when provided with a multimedia summary containing both visual and verbal formats. This type of information supports the value of text pictorials and the ideas of Paivio (1986).

A search of college level biology texts establishes the need for the development of a more efficient method to measure electron micrographs. In four texts analyzed by this researcher there were approximately 539 micrographs. This large number affirms the importance of the students’ need to acquire a knowledge base in micrometry prior to college. To aid the viewer, accompanying diagrams usually include a scale bar or an indication of the number of times (e.g., 250x) structures were magnified. Often the scale bar has been omitted from the diagrams of the text. Thus the student is provided no clue as to relative size of the structures being imaged.

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Pilot Study

The researcher made a videotape at LSU using the Scope-On-a-Rope to compare two types of measurements commonly used in micrometry, the scale bar and the MicroMeasure™ system. The Scope-On-a-Rope is a high-tech, industrial, hand-held, ring-lighted, tethered, video-probe microscope first introduced to biology education in 1991 by J. H. Wandersee and M. C. Henk of LSU, along with other members of the Exploring Microstructures™ Group.

The stage area of a high resolution videocamera is illuminated fiber-optically and held next to the specimen or surface to be imaged. The resulting image is displayed on the large cathode-ray tube of a video monitor for classroom viewing (J. H. Wandersee, personal communication, March 2, 1999).

In a series of experiments students are asked to estimate sizes of five items using various approaches: (a) the head of a louse, (b) the head of a pin, (c) a seashell, (d) a pollen grain, and (e) a poppy seed. There are 20 frames, four for each item, which are projected on the monitor. Participants have to estimate the size of the item by visually applying the scale bar (see p. 10) or the MicroMeasure™ system (see Appendix G), one of which is provided with each frame. An answer sheet is provided to record estimates of each of the 20, equally timed frames.

An introductory segment explains the task to the students so that the instructor does not have to teach or give instructions. There are two sample questions at the beginning of the video preparing them for the procedure. This
ensures that all students will have the same information before marking their answers. An answer sheet is provided for each student.

To test the hypothesis that students would be able to estimate size with the MicroMeasure™ system method more easily than with the scale bar, the researcher tested 156 local high school students and 144 college students. A paired sample t-test failed to show a significant difference in the two methods of estimation for the high school students \( (t = .08, df = 155, p \text{ value } = .468) \) and the college students \( (t = .004, df = 143, p \text{ value } = .499) \). The tabulated responses indicated that the students' size estimations using the MicroMeasure™ system were more favorable but not with the expected margin. Orally, however, the students responded in favor of the MicroMeasure™ system. They reported that calculating estimates with the MicroMeasure™ system was easier than calculating estimates with the scale bar.

Several facts may explain why the results from video were more successful, but did not significantly differentiate the more effective method of representing scale as hypothesized. Students were allotted a response time of only 15 seconds for each estimation. Items viewed were interesting and, if students had spent too much time examining them, they might have been careless or hurried in their estimations. Some students might have had difficulty readjusting the variation of scale between estimates before seeing the video, and the fact that specific structures were to be measured (e.g., head of louse, width of shell) might have caused some hesitation, thereby decreasing the amount of time left for estimating. All students should have had prior exposure
to the concepts that were involved in making the estimates, but if they had not, they might have encountered difficulty. Students might need more practice with the new system before being tested. Also, a small percentage of students might not have taken the exercise seriously. The researcher thinks that had more time been allotted for each task, there would have been greater variation in the results. The video was used with participants chosen for the case study of this dissertation, and the amount of time allotted for participant's response for each frame was increased. More practice time was also allowed prior to direct the procedures.
METHODOLOGY

Rationale for Research Methods

The qualitative method of research was chosen for this study because it best fit the explorative nature of the data which was to be collected. The following research subquestions were investigated: (a) How do precollege science experiences influence the undergraduate biology student's concept of scale? (b) How do college biology students respond to three different representations of scale on electron micrographs? (c) How are the college biology student's concept of scale and interpretation of electron micrographs mutually influential? The questions determined the method chosen to direct the procedure of the investigation. The two metaquestions of the dissertation title were considered along with the above specific research questions.

The strategy for studying the phenomenon of how students struggle to understand scale was designed to produce a holistic multiple-case study. According to Yin (1994), a study is holistic if there is a single unit of analysis. The student's narrative of scale is the unit of analysis for this research. Data were collected from four participants. Using data from multiple cases produces evidence that is more compelling and usually more robust (Herriot & Firestone, 1983). This case study enabled investigation of the empirical topic, the concept of scale, with procedural protocol; i.e., the ordered manner in which the researcher followed prespecified protocol during the investigation. Each of the four cases was a complete study. Information from each case was compared to
and contrasted with that of the other three cases. Case study procedure was the research strategy chosen for this investigation because it allowed for the assessment and understanding of complex social events. Being able to incorporate various techniques in data collection—such as interviews, concept maps, and direct observation—provided a more comprehensive research strategy for theory development.

The metaquestions being explored were "how" questions that "asked about a contemporary set of events over which the investigator has little or no control" (Yin, 1994). According to Yin, these conditions favor the use of case study as the research strategy. While direct observation and systematic interviewing are available techniques, Yin states that the strength of the case study is the researcher's ability to draw evidence from a variety of sources.

**Researcher**

Teaching microscope skills to students for approximately 25 years has provided the researcher with innumerable occasions to check students' tactics. This experience has resulted in perfecting of her instruction for using the microscope as well as for informing students about the benefits of the instrument for humanity. Her observation has been that enlightenment allows students to transfer knowledge gained by microscope instruction to other topics.

Personal bias is inevitable because the researcher was the primary source for the determining the type of data collected and the method for analysis of this data. Awareness of a positive bent in favor of microscopy was
not problematic in the actual interpretation of the data. It was the investigator's moral obligation as a teaching professional to report the findings in an honest and ethical manner.

**Setting**

The site selected for this study was the institution where the researcher is employed, McNeese State University. Microscopes were readily available in the general biology laboratories. Light microscopes are used throughout the semester in the freshman laboratories and case study participants had access to them.

The researcher's laboratory allowed privacy and freedom from interruption while the research sessions were being held. The laboratory was located on the second floor of one wing of the science building, Frasch Hall. Meetings were held when no classes were scheduled so that there were no interruptions. Students had access to new microscopes (recently obtained through a grant awarded to the researcher and several of her colleagues) to perform their activities.

**Participants**

Students from the researcher's freshman classes were asked to volunteer for several sessions so that she could collect data for research purposes. The first two females and two males to volunteer were accepted as the participants. After volunteering, students were told that the researcher would compensate them (U.S. minimum hourly wage, $5.15) for their meeting
time. The researcher asked for the volunteers to be students who had not previously been enrolled in a freshman biology laboratory so that each would have had approximately the same exposure to the microscope. This ensured relative homogeneity of the participants.

First-year students who attended high schools in the South frequently have similar science backgrounds. However, one could certainly argue that classroom variables, ranging from the teacher to the text, and to the quality of scientific investigations in the classroom, could be responsible for marked differences in the student population. Variations in the laboratory quality and infrastructure in Southern school systems exist, of course. Sometimes the differences are due to revenue and sometimes to the teacher's personal experience with the subject of science. Such differences produce various gaps in the knowledge base of the freshmen entering McNeese. For this reason, college instructors are unable to make reliable assumptions about their students' understanding of laboratory procedures. Information about the students' prior exposure to scale and microscopy is essential.

**Gaining Access**

The administration of McNeese State University had no problem with use of the laboratory for conducting research. Permission was granted by the McNeese State University Institutional Review Board. Sessions with students were scheduled in a laboratory room only when interruptions would be unlikely. A “Do Not Disturb” sign was posted outside the laboratory to assure that accidental disturbances did not occur.
A letter of consent explaining research methods and the nature of their involvement was prepared for distribution to the students (see Appendix B). This was presented to them during the first session. Participants were informed that the data would be aggregated in order to protect their anonymity and confidentiality.

**Sources of Data**

The researcher incorporated a variety of data-gathering methods to seek answers to relevant issues which were chosen for research. Initially, it was difficult to identify the most important source for analysis. Multiple case studies provided opportunity for employing such strategies as interviewing, coconstruction of concept maps, writing an autobiographical essay pertaining to the concepts, journaling, gaining information from a laboratory procedure, performing an exercise on scale recorded on video, doing an exercise of scale identification incorporating the three scale depictions, and analyzing results of a questionnaire.

**Interviews**

Interviews were a major source of data gathering. Two strategies were followed: key-informant interviews and elite interviews. Context and purpose identified in the data determined the strategy which was used.

Personal initial interviews with each of the participants provided data about the background of the students. Interviews lasted 30 to 40 minutes (see Appendix D). These aided in assessing the progress of each student as new
concepts were introduced in the progress of the project. Respondents answered structured, open-ended questions. Personal data relating to their educational background was sought as well as other information related to the research. A postinterview session determined the extent of each student's progress (see Appendix E).

Elaborations of the interviews were recorded. Data included self-reflections on the researcher's role and rapport, reactions of the interviewee, and extensions of interview meetings. Audiotapes and transcripts were made of each interview. A personal journal recorded the researcher's impressions during the interviews.

Participants in the research were spontaneous volunteers—not students who were carefully selected to share their special knowledge; however, each informant had communication skills, special knowledge, and talent that he or she wanted to share. Elite interviews (Dexter, 1970) generated ideas, policies, and generalizations which were essential for the success of the interviews. The researcher conducting the interview was interested in soliciting each participants' perspective of the research topics. Merriam (1988) says that it is not necessary for the respondent to "have a broad understanding of the culture" (p. 76). Because of the nature of the research, respondents assumed the dual role as key informant who had valuable information pertaining to educational development of the concepts under study and as investigator who carried out projects assigned by the researcher. Students were identified by the researcher as key-informants during the introductory session when they acknowledged that
they had been educated in South Louisiana. The researcher was not knowledgeable about the presentation of the concepts of size, measurement, and scale in grades K-12. Informants were relied on to provide valuable information when asked specific probing questions by the researcher.

**Concept Mapping**

Concept maps provide a way for anyone to express the relationships between ideas. Novak and Gowin (1993) note that “in Ausubelian learning theory terms, a teacher needs to know what relevant concepts can serve as the framework for subsumption of new material” (p. 100-101) and that indeed “Concept maps are a simple tool for assessing where the learners are” (p. 101).

There were two coconstructions of concept maps (see Figures 5, 6, 7, & 8). One occurred the fourth week of data gathering and the second occurred the seventh week. To check the student’s present understanding of measurement, scale, and micrometry, the student and researcher constructed a concept map on a blank piece of paper. As a record of the event, the maps were recopied verbatim, using computer-mapping software for greater legibility.

Ruiz-Primo, Araceli, Schultz, Li, and Shavelson (1999) concluded that “low-directed tasks seemed to provide students with more opportunities to reflect their actual conceptual understanding” (p. 15). This technique also best reflected students’ knowledge differences when compared to fill-in-the-line and fill-in-the-node techniques. High-directed and low-directed tasks refer to the amount of information provided to the students. Participants of this research were low-directed because they decided the connectedness of concepts, the...
positioning of concepts on the map, and the linking words between concepts. Baxter and Glaser (1998) describe this mapping as a “content rich-process” (p. 40).

Concept maps were designed to probe a student’s understanding of a subject. A lesson about concept mapping was presented at the beginning of each participant’s concept map session. The reason for the researcher’s involvement with the process was to allow each participant to exhibit the same proficiency in concept mapping.

Twelve terms were presented to each participant as an exercise for coconstruction of a concept map; coconstruction of concept maps was developed at LSU by Eleanor Abrams and James H. Wandersee. The following concepts were chosen because of their importance and relationship to scale—the theme of this research: scale, size, measurement, microscope, magnification, ocular, stage, field of view, lens, resolution, and low and high powers. The purpose of placing this exercise early in the research was to probe the student’s immediate understanding of the concepts involved in the research. Data from this procedure and from the autobiography helped answer the question “How do precollege science experiences influence the undergraduate biology student’s concept of scale?”

Graphics

Another assessment device requiring the students’ understanding of the concept of scale was their responses to three representations of scale: the scale bar, the Henkograph, and the MicroMeasure™ system. The Henkograph
is a frame-based, micrograph measuring system for micrographs. Pictures of stomates, statoliths, leaf structures, and parenchyma cells were scaled for each of these representations (see Appendix F). Responses from the students to these scaled micrographs were elicited during the seventh session. This query was intentionally placed later in the data collection process so that most of the students would have developed a clearer understanding of scale and its relationship to micrography. Data from this query was used to answer the second research question, "How do college biology students respond to three different ways of representing scale on electron micrographs?"

**Autobiographical Essay**

Each participant was asked to trace her/his memory of the development of the concept, measurement, during her/his life (see Appendix G). This essay, a personal document in the form of an autobiographical essay, was composed specifically for scientific interest. It was written the third session of the data collection period.

**Videotape Questionnaire**

Their perceptions of scale were determined by responses of students to several visual probes. One technique was the recording of their recognition of scale on a video. This was the "Scope-On-a-Rope" video comparing the scale bar and MicroMeasure™ system of measuring which the researcher discussed earlier in previous findings. The researcher used it the fifth session of data collection to assess the participant's preference between two types of
measurement commonly used in micrometry, the scale bar and the MicroMeasure™ system which are two of the three interpretations of scale currently used with electron micrographs. Data from their responses to the video were helpful in answering the third question, “How are the college biology student’s concept of scale and interpretation of electron micrographs mutually influential?” Results were analyzed to assess the student’s skills in visualization of scale.

An introductory segment during which the researcher gave instructions prepared students for the exercise. This ensured that each student had the same information before selecting an answer. At the beginning of the video two sample questions were posed. An answer sheet was provided for each student (see Appendix A). In contrast to the pilot study referred to earlier, students were allotted as much time as they needed for their responses. Additional time for viewing each frame was suggested by colleagues who had viewed and critiqued the video.

Data Collection Techniques

As data were sorted, they were sequentially numbered and arranged in chronological order. The many types of data needed to be kept separate so that particular kinds were easily retrievable. This organization was the first step in managing the substantial amount of material which resulted from the research.
Transcripts

Much of the data from the research was audiotaped or videotaped. The audiotapes from the interviews were transcribed on a word-processing program (see Appendixes D & E). The videotapes provided a reference for student nonverbal behavior during the process of data collection.

Journaling

Journaling has a broad-ranging application for credibility, transferability, dependability, and confirmability (Lincoln & Guba, 1985). These are the four components of trustworthiness. Information recorded in the log can denote possible biases the researcher has toward the results. The diary provides a daily record of the researcher's entries about methodology decisions. The journal entries attest to the integrity of the analyses.

Data Analysis

Unitizing and categorizing described by Lincoln and Guba (1985) proved to be the most practical approach for organizing the data collected by the researcher. Using the metaquestions as a guide, the researcher has organized the findings from student responses from her own observations. The researcher has relied on data triangulation to interpret the results but has tried to avoid "becoming so taken up with methods that the substantive findings are obscured" (Denzin & Lincoln, 1994, p. 215).
**Constant Comparative Method**

The constant comparative method was formulated by Glaser and Strauss (1967). This method of generating theory, which involves the choice of several types of comparisons, was possible with data choices the researcher used for her study. The multiple case studies provided a rich source for this technique.

Data from autobiography, personal interviews, concept maps, questionnaires, and observations of videotapes and laboratory activities were assembled in this study. The constant comparative method was applicable to each kind of qualitative information. The three questions which the researcher addressed in the study were closely related. Assessment of prior knowledge could only be addressed through directed questioning, whether in print or verbally, through student-generated memory writing (autobiography), and through follow-up questioning based on the researcher's observations.

**Triangulation**

Another effective method of analysis employed the technique of triangulation. Denzin (1978) developed this type of analysis so that the researcher would have more than one reference point for interpreting data. By clarifying meaning, triangulation reveals the different ways that events are viewed (Flick, 1992). This shared analytical approach improves “the probability that findings and interpretations will be found credible” (Lincoln & Guba, 1985, p. 305). Data sources for this study consisted of initial interview, autobiography,
a ten-point questionnaire, an initial concept map, a video presentation, a microscopy experiment, electron micrographs, a final concept map, and a final interview.

Triangulation "can imply either different data collection modes . . . or different designs. . . . Different modes of data collection [use] any that come logically to hand but [depend] most on qualitative methods" (Lincoln & Guba, 1985, p. 306), but Lincoln and Guba contend that using multiple theories as a technique "seems . . . both epistemologically unsound and empirically empty" (307). Thus the researcher focused on triangulation through different modes of data collection, and "we believe it to be the case that the probability that findings (and interpretations based upon them) will be found to be more credible if the inquirer is able to demonstrate a prolonged period of engagement . . . evidence of persistent observation . . . and different sources" (Lincoln & Guba, 307).

A research team at McNeese State University consisting of three biology professors and an environmental professor reviewed this research at regular intervals to validate the investigator's attempt to reduce bias in interpretations (Lincoln & Guba, 1985). The researcher is the one reporting interpretation of the data. Other professors provided multiple perspectives which seem to strengthen the content validity of the research.

Coding

Various types of coding are suggested in the literature, but some coding categories are always necessary in order to sort data into patterns—"a crucial
step in data analysis" (Bogdan & Biklin, 1992, p. 166). Bogdan and Biklin list
the following coding families, noting that multiple coding families are used in
any one study: setting/context codes, definition of the situation codes,
perspectives held by subjects, subjects' ways of thinking about people and
objects, process codes, activity codes, event codes, strategy codes,
relationship and social structure codes, methods codes, and preassigned
coding systems (p. 166-172).

The researcher coded data three ways: (1) according to key concepts
(size, measurement, scale, and microscopy); (2) various data collection modes
or data types (a source code, using numbers 1-9); and (3) according to levels of
understanding of key concepts (complete understanding, partial understanding,
no understanding, partial misunderstanding, complete misunderstanding, and
not applicable). Table 6 utilizes these codes in expressing data into categories.

Time Frame of Study

After the students were selected for the research, data collection began
June 1999 and continued through August 1999. The format of each session
required scheduling one to one and one-half hour meetings for assessing
specific concepts.

The following is an overview of each segment of data collection.

1-Informational Meeting

Letters of consent were given to the participants when they volunteered
so that all knew the scope of their participation (see Appendix B). The

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researcher also obtained a schedule from each student so that meetings could be conveniently scheduled.

An initial interview was scheduled for the following week for basic introduction questions (see Appendix D). This meeting set the tone for future events.

II-Initial Interviews

These interviews familiarized each student with the nature of the research.

III-Group Session

All of the participants met together for the first group session, where they were asked to write an autobiography about their educational experiences with the concepts of measurement and scale from their earliest memory to the present time. The researcher did not present specifics for construction of their papers with the exception of explaining what the term scale implies. A simple definition was all that was necessary. Information from this meeting aided in interpreting the first research subquestion: How do precollege science experiences influence the undergraduate biology student's concept of scale?

IV-Individual Session

A 10-point questionnaire was given to each of the students prior to coconstruction of her/his concept map to help the researcher determine her/his current understanding of scale (see Appendix C). It was the researcher's assumption that there would be a correlation between the score on the
questionnaire and the ability to interpret micrographs. Completion of the questionnaire was not a timed task.

In this session the researcher took approximately 15 minutes to explain the concept map, the procedure for constructing one, and provide a hard-copy example; she also provided time for additional help through questions and answers both immediately following her explanation and during the process itself. The participants were then asked to coconstruct a concept map. Twelve terms were supplied on a sheet of paper for them to arrange in a hierarchical manner with linking words. The researcher provided blank paper on which participants drew their concept maps. They were allowed as much time as they needed.

V-Group Session

The “Scope-On-a-Rope” video, used in the pilot study, was shown to the students. Their responses were placed on an answer sheet and used as a data source.

VI-Group Session

During this session the researcher presented an experiment on microscopy because the microscope is useful for observing how effectively participants apply their knowledge of scale to microscopy. First the presenter reviewed the microscope, its parts and usage; she then demonstrated how to make a wet mount. Next, the students were allowed to examine their microscopes and measure the field of view with a transparent millimeter ruler.
After measuring the field of view, students were provided a slide to make a wet-mount of the aquatic plant *Elodea anacharis*; students had to draw their specimen on both low-power and high-power magnification. The experiment had specific learning objectives for the students (see Appendix I). Their responses revealed whether or not they understood linear units of measurement in the metric system. Each student drew sketches of the aquatic plant *E. anacharis*. For the drawing to be correct, the student must have grasped the concept of scale. Again, students were not timed for this activity.

The microscope is useful for applying the concept of scale. Having the students perform some simple experiments developed concepts such as scale, field of view, total magnification, and resolution. At this time it was also necessary for participants to become familiar with metric measurement if this had not yet been accomplished during their educative experience. Using overhead transparencies, they reviewed the parts of the microscope and metric terminology.

The aquatic plant *E. anacharis* was the subject for the students' measurement of cell size. Each student measured the field of view and then was asked to sketch to scale and label one of the plant cells on low and high power. The sketches were made inside a circle drawn with a Petri dish. Each circle represented the field of view.

This exercise is based on the work of Tobin (1990) on cooperative learning in laboratories. The students were attentive to the researcher's introduction, remained on task, and were motivated about learning and
assisting each other. There were several supportive exchanges between the students as they completed the assigned task, as if "imitating [sic] a team of scientists who work in research" (Lazarowitz & Tamir, 1994, p. 114).

Appointments were made for Week VIII, during which each student determined her/his preference of scale representation—the MicroMeasure™ grid, the Henkograph, or the scale bar.

VII-Individual Session

The second coconstruction of a concept map was performed with each student individually to see if her/his understanding of scale had changed. The video presentation had provided students with some experience in visualizing size of objects and the representation of different scales, but the researcher did not explain the three types of scales. Students arranged a selection of electron micrographs—scaled with the scale bar, Henkograph, or MicroMeasure™ system—in order, from the easiest measurement scale to the most difficult (see Appendix F). Appointments with each of the participants were scheduled for final interviews.

VIII-Individual Final Interviews

The responses to questions during this interview aided in the assimilation of theory (see Appendix E). They also helped in identifying future research questions.

Table 1 illustrates scheduling.
Table 1

**Sequence for Data Collection**

<table>
<thead>
<tr>
<th>SESSION</th>
<th>PURPOSE</th>
</tr>
</thead>
<tbody>
<tr>
<td>I Introductory (Group)</td>
<td>Informational; distribution of letter of consent</td>
</tr>
<tr>
<td>II Individual initial interviews</td>
<td>Informative</td>
</tr>
<tr>
<td>III Group</td>
<td>Autobiography</td>
</tr>
<tr>
<td>IV Individual</td>
<td>10-point questionnaire; coconstruction of concept map</td>
</tr>
<tr>
<td>V Group</td>
<td>Video presentation</td>
</tr>
<tr>
<td>VI Group</td>
<td>Microscopy experiment</td>
</tr>
<tr>
<td>VII Individual</td>
<td>Electron micrographs and scale; concept map</td>
</tr>
<tr>
<td>VIII Individual</td>
<td>Final interviews</td>
</tr>
</tbody>
</table>

**Ethical Issues**

A thorough examination of ethics has been conducted by many in the field of qualitative research. Although codes established by individuals as well as organizations designate essential guidelines for researchers, personal and professional problems may arise. Soltis (1990) reminds the evaluator of the Kantian ethical imperative “to treat persons as ends in themselves and not as means to our ends” (p. 252).

The most common ethical problem of evaluative research concerns decisions about which results are to be published (Soltis, 1990). Self-interest
should not bias what is reported. A significant moral code of honesty and
fairness is essential in evaluation.

Identities of the participants were protected by assigning pseudonyms.
Participants used pseudonyms on all paperwork that was turned in for data
translation. Specific information about students participating in the research
was not to be in the researcher’s conversations with colleagues at the
university.

At the onset of the study, informed consent letters describing the nature
of the project were presented to the students (see Appendix B). The researcher
explained to them that they were privy to data analyses prior to dissemination.
All data were aggregated in order to protect the anonymity and confidentiality of
each participant.

The following diagram (see Figure 4) represents the bottom-up flow of
the data during illumination of the dissertation questions. Group and individual
participant-researcher conversations were built into the research design to
enhance inter-subjectivity. Munro (1991) urges that the relationship of
researcher and participants be an inter-subjective process of meaning-making
by collaboration and reciprocity.
How do selected introductory college biology students struggle to gain an understanding of scale and measurement?

How can microscopy-based learning activities enhance students' understanding of scale and measurement?

How do college biology students respond to three different representations of scale on electron micrographs?

How do precollege science experiences influence the undergraduate biology student's concept of scale?

How are the college biology student's concept of scale and interpretation of electron micrographs mutually influential?

- Interviews
- Autobiographies
- Concept Maps
- Graphics
- Videotapes
- Lab Exercise

Figure 4. Research diagram
Results and Discussion

Session I: Introductory (Group)

Session I: Informational. Distribution of Letter of Consent

The research procedure was described to five volunteers from the summer 1999 semester lecture section of Biology I (Bio I), three females and two males. During the introductory session the participants were encouraged to ask questions. When scheduling was discussed, one student was dismissed because she had been out of school longer than the other participants. Maintaining relative uniformity in participant age was important to the design of this study. At this time the reason for assigning pseudonyms was addressed and names were chosen by the four final volunteers.

Letters of consent were distributed and their significance was explained (see Appendix B). The group was dismissed after each had submitted a copy of her/his schedule. The researcher felt that future appointments could be arranged with relative ease.

Session II: Individual Initial Interviews

Session II: Informative

The questions posed precede the respondents' replies. Multiple questions prior to answers indicate that students' answers included additional information. The videotaped interviews began with inquiry about the student's classification and major. None of the participants was a science major (see Appendix D).
Most research questions were answered without delay. Occasionally students asked that one of the terms be explained. The students did not hesitate to answer the question after the researcher had defined the term. Table 2 provides answers for questions one and two.

1. What are your student classification and major?
2. Would you please tell me about your background in science.

Table 2

<table>
<thead>
<tr>
<th>Name</th>
<th>Home</th>
<th>Classification</th>
<th>Major</th>
<th>Science Background</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bill</td>
<td>SE LA</td>
<td>Senior</td>
<td>Mass Communications</td>
<td>Biology, Chemistry, Physical Science</td>
</tr>
<tr>
<td>Frank</td>
<td>SW LA</td>
<td>Sophomore</td>
<td>Political Science</td>
<td>General Science, Biology, Chemistry, Physics</td>
</tr>
<tr>
<td>Lauren</td>
<td>SW LA</td>
<td>Freshman</td>
<td>Mass Communications</td>
<td>General Science, Biology, Chemistry, Physics</td>
</tr>
<tr>
<td>Louise</td>
<td>SW LA</td>
<td>Junior</td>
<td>Mathematics Education</td>
<td>General Science, Biology I &amp; II, Chemistry, Physics</td>
</tr>
</tbody>
</table>

3. What activity did you enjoy most in science?

Bill stated that what he had enjoyed most about biology was frog dissection. Because Frank liked math, physics had been his favorite subject. Lauren's scientific interest had been stimulated by discussions with her dad, an anesthetist, about operations and the human body. Recalling her experiences, Lauren said the following:

Um-m, I guess as far as in general. My dad is an anesthetist and during dinner sometimes he would talk about operations and
whatever and that was always really interesting to me just when he would talk about the human body and stuff like that when we were eating.

Louise’s most enjoyable experience in science was dissection of the fetal pig during her sophomore year.

4. What was your earliest experience relating to the size of something in your environment? / 5. As you got older, did your impression of this experience change?

Question 4 asking the participants to recall their earliest experience relating to size caused them the most difficulty. Because all of them had difficulty with size, they were told to relate their experience to their own size when they were younger. Providing this relationship made their responses more spontaneous.

Bill was given a copy of the questions to read as they were asked because he frequently wanted them to be repeated. The others seemed to have no need for such an aid. Bill’s first interest in size was in relation to shooting basketball goals. He recalled that the taller he grew, the closer the goal seemed to him even though, at the free throw line, he was the same horizontal distance from the basket. Frank’s early recollection was that of comparing his shoes and clothing to those of his parents. He eventually outgrew his parents in both categories. Lauren’s recollection of size involved either halved or whole graham crackers. She also mentioned that she had traveled to New York City and had visited the Empire State Building where she had wondered how many people, standing on top of each other would be...
needed to reach that height (people per story times number of stories). Finally, Louise said the lake on which she lived, Lake Charles, had seemed to be the biggest thing in the whole world. Standing on the wharf, she thought she could see New York. She has since realized that the lake is much smaller and that the tall structures on the other side are actually chemical industries.

6. Do you remember your first school task in which magnification was involved? / 7. Was there anything special about the task that made it memorable?

For two of the four students, the first school task pertaining to magnification was an exercise in biology regarding microscopy. Lauren had viewed cork cells with a microscope in the sixth grade. She also had studied parts of the microscope in high school. A recollection of having used various lenses to change the size of objects was a memory of Lauren's experience with microscopy. Louise had used the compound light microscope to view bacteria and hair and also to measure planarians, aquatic flatworms. Her teacher had allowed the students to have an extended period of time to perform various experiments with the worms. They had fed and raised them, dissected them, and recorded their growth by measuring with a "special ruler."

The other two students had also enjoyed their experiences with the microscope, although they did not remember the first task specifically. Bill was unable to recall what he had seen magnified, but a plant, frog, and a variety "different elements that you find" were among his recollections. His most memorable impression was of having been "a scientist for a minute." He was
referring to his use of the microscope. Frank described using a magnifying glass and prism in elementary school science. Going outside to look at “stuff” with magnifying glasses was memorable. He said that he had probably used a microscope in general science and that he was sure he had had access to one in high school. He was sure he had learned the parts as well as viewed “stuff.” Clearly, the experiences of all four were positive.

8. Prior to high school were there references to size comparison or scale that you recall? What were they?

The question concerning references to size comparison, or scale, prior to high school prompted each participant to question what was meant by scale. Simply defining scale for them proved to be inadequate, so the scale bar of maps was given as an example. In his interview Bill began to talk about how Louisiana and Texas compare in size. When he was younger, he said he had wondered why they were not all the same size. Frank said he was aware of having worked with map scales in junior high school and microscopic magnification in high school. From social studies or science, he recalled his concept of depth in relation to measurement. At the conclusion of his interview, Frank described an environmental science experiment in his freshman year of high school. During a study of planets, his teacher had given students ten oranges and a piece of construction paper. Using the hallway, they had had to place the oranges at distances relative to their actual position in the solar system. The experiment had impressed Frank particularly because the sun was at one end of the hallway and Pluto was at such a great distance from it.

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Lauren recalled having to compare the English and metric systems of measurement in elementary school. She commented that, in her junior high school, the metric system had not been used and that she would have liked to have designed a way to change that. She found a system based on ten to be much easier than the English system of measurement. These three participants struggled with the answers to the eighth question. Louise was the only one who was completely at a loss to recall having had any experiences with size comparison or scale. She just said that it had been so long ago that she could not remember.

9. Did you have a “hands-on” experience with the microscope in high school?

All students reported having had experience with the microscope in high school and answered the question about “hands-on” experience with the microscope as one of their magnification examples. Bill had had lengthy instructions on proper microscope usage with the teacher’s having stressed the expense of the device. Frank, Lauren, and Louise each had received instruction on parts of the microscope and on proper usage of the microscope. All had clear memories in response to this question.

10. Were you ever asked to do a measurement exercise with the microscope?

When participants were questioned about a measurement exercise with a microscope, they understood microscopic measurement to mean comparing the magnification of various organisms rather than actually measuring them.
with an instrument. Bill said he had done this. Frank understood the question but said that he had determined only the magnification of the specimens. Lauren had not measured anything with the microscope—only changed magnifications. Louise said she had measured planarians with a “special ruler” as she had previously answered in her most memorable experience involving magnification. Recognition of creating different image sizes by changing magnifications was her most significant experience with the microscope.

11. Can you think of any reason that the understanding of size, scale, and measurement would benefit you in your future?

Benefits of size, scale, and measurement seemed to puzzle all the respondents. Bill, an athletic enthusiast, applied his knowledge of these concepts to his body. Being a certain weight was a determining factor in how fast he could run and how high he could jump. If there were a seven-foot tall player in front of him, Bill said that he would have to strengthen certain muscles of his body in order to jump as high as he needed to in order to make the goal. Scale was a difficult concept for him, but the researcher explained that he was applying this idea when he talked about the distance he wanted to jump in order to get above a certain height. He explained as follows:

Ya’ know measurement comes into play there because like ya’ gotta work out a certain amount of time. Like say—if I have a thirty-five inch vertical mount, I would want the forty inch vertical, so I would have to do certain things that would help my jumping ability.

Overall, his comments about the concepts parallel Amato’s (2000) assessment of how human beings think about the microcosm:
First, what is obvious but fundamental, human beings think and feel anthropomorphically. We shape our images of things to fit our body size, feelings, interests, and moral and dramatic purposes. We cannot escape making ourselves the measure of all things big and small. Our fundamental emotions and wants will not, at least over the long term, be inhibited by new and subtle sciences. (p. 170)

Frank first answered quickly, “Um, not really.” Then he expanded:

Well, maybe not from a scientific viewpoint just because that’s not my major but like it’s you know, um, like just measurement itself, you know. Understanding like how far something away is, you know, how do I relate that to my life, you know, like realizing that I have to plan this out because of time wise like how far to drive and how long you know how small something is. Like if you’re reading a map, you know oh well you have the whole state of Texas there. Well, you know, this means so much and stuff like that. I can see how that could be beneficial.

The two females were more general in their responses. Lauren seemed to think that because she was going into journalism that she would not benefit from knowing these concepts. She conceded, however, that she might need to know something about how big some things are. Louise gave an immediate positive response but had some difficulty explaining why. She concluded that you just needed to know that you were not as small as some things and not as big as others.

Session III: Group

Session III: Autobiography

In their autobiographies the participants were asked to trace, as clearly as possible, their memories of the development of the concept of measurement from preschool through high school.
Pinar (1988) describes the autobiographical method as “opportunities to return to our own situations, our ‘rough edges,’ to reconstruct our intellectual agendas. The focus in such work is the felt problematic; its method is intuitive” (p. 148). Intuition is what the researcher relied on for interpreting situations described by participants in their autobiographies.

Bill’s recollections seemed to begin with familiar references to size with sayings such as “Size isn’t everything,” “The bigger they are, the harder they fall,” and “She’s as small as an ant.” In junior high Bill was told that school was “two clicks away,” a phrase which gave him the idea that it was much closer than it actually was. He was aware that when he became six feet tall that he was thought of differently not only by his peers but by coaches as well. Bill said that coaches notice a person’s height before they notice his criminal record or bad teeth. Size has always been an important factor to Bill because of the height and weight factors that are so important for participation in sports. When driving from New Orleans to Lake Charles, Bill finds time is more of a factor than miles. He finds the same comparison as he travels back and forth to school: time is his measure rather than distance.

Frank’s earliest recollection about measurement was that “everyone older was bigger and stronger than I was.” When he thought of early childhood, he recalled comparing shoe sizes. He also remembered how small he was as he sat in his father’s lap and tried to reach the pedals of the car. Graduation from a tricycle to a bicycle helped him realize that he was growing. At his grandmother’s house his height was regularly recorded on the doorpost.
bathroom scale was also a device for conceptual development of size, and there was excitement when he first exceeded one hundred pounds. He also acquired siblings and became the big brother.

Elementary school added more experiences that related to his body. A second grade teacher used a "walking ruler" to teach the students measurement. The length of one foot was indicated by a clicking sound. So it was with this activity that distances were measured from his classroom to the principal's office, restroom, and cafeteria. Art classes also presented Frank experience with measurement as outlines of hands and body were traced and then used for comparison to other students' hands and body outlines. These fun-filled measurement activities made them memorable for Frank.

Scale and distance awareness was raised at vacation time. By using the map and calculating distance, Frank learned how long it took to reach a specific destination. Playing with puzzles of the United States also helped in his understanding of distance. He credits his dad for this learning experience, but said it also kept him from asking, "How long until we get there?"

In middle school and high school, Frank noted that his use of measurement began to be more scientific. Microscope usage in the seventh grade provided the magnification for seeing individual cells. Time, measurement, and scale were used frequently. With 10 oranges and a yard stick, Frank and his peers were able to visualize the distance of the planets from the sun. "In the 9th grade my science teacher gave us 10 oranges and by following an outline and using a yard stick, we were able to see the distance of
the planets in our solar system . . . from our sun," writes Frank. In the band drills, taking eight steps for every five-yard line was crucial to formations during drill. Learning to drive was a nightmare for Frank when he had to estimate size and distance needed for parallel parking. "Another memory—or should I say nightmare—of size and distance was the first time that I had to parallel park," Frank recalled. In his senior year he measured the distance and recorded the time for running and walking a specific distance while performing certain tasks. He calculated the mean from this information to explain differences in the height and weight of individuals. Frank was consistent about the influence of the conceptual development of measurement throughout his life.

Lauren had recollections of kid-sized furniture in her environment during her preschool years. At that age, she was well aware that her parents were larger than she. When Lauren shopped with Mom, the cereal was too high for her to reach but not for her mom. When she played with her dolls, she found that pairing Barbie with G. I. Joe was difficult because of their size differences. In first grade her tall, thin teacher had an oversized brown box for a desk, and hiding under the desk was fun for students. At that age she thought older kids were giants. Her books were filled with large print so that reading was easier, but learning that there were 12 inches in a foot was about the extent of measuring in elementary school.

Measurement became more sophisticated for her when metric units were introduced in middle school. Lauren was puzzled about why America did not use this system. The ease of this method impressed her. "And I remember
wondering in junior high why we didn't use the metric system. And then trying to figure out how I could change that," said Lauren.

In high school, chemistry and physics brought on unexpected problems for Lauren as she learned to deal with moles, distance, and mass. "With the introduction of the mole (6.02 x 10²³ particles) and the detailed examination of distance and mass, measurement became a real part of what happens every moment of life," she wrote. When learning how to drive, Lauren attempted to calculate stopping distance if she were traveling more than thirty-five miles per hour. Biology did not require much measuring, Lauren wrote, but she had learned cell size, in relation to the organism in which it resides, is important.

Louise recalled a particular rocking horse that had seemed as large as a real horse to her as she played on it. After retrieving it from the attic when she was older, Louise said that it surprised her that it was tiny—only two feet tall and about three feet in length. Her visualization of how large it had seemed to her is still very vivid. "In my head I can still picture it the way I used to," Louise remembered. Some visual memory is of photographic quality (Neisser, 1982; Solso, 1995).

The third grade was when Louise realized that she really was not familiar enough with the concept of measurement to transfer a length from a piece of paper to a chalk board. After becoming familiar with measurements on a foot-long ruler, a classmate had been asked to draw a four-inch line on the board. Louise thought that he had not drawn it long enough. When the teacher measured it, the line was over a foot long. Louise concluded,
I remember being so surprised and thinking to myself that I really hadn’t grasped the concept of measurement yet. I could do it when it was on my usual size sheet of paper that I had learned on, but when it came to bigger or smaller things, my concept was distorted.

Louise recognized that she had a great deal to learn about the concept of measurement.

In middle school, with the transfer to a new part of town, Louise thought the distance to her school was much farther from her home than the elementary school that she had attended. As she got older and traveled more, Louise developed a different concept of distance. After living in Dallas for two years, she found distance seemed to get shorter. She understood, however, that the distance remained the same although the time required to travel became less.

In high school chemistry, the subject of the size of atoms was the cause of much contemplation for Louise. Despite the teacher’s explanation about their small size, Louise thought that the atoms are not really that small but that people are just larger. “I remember thinking that maybe they aren’t that small, it’s just that we’re a lot bigger than them. That doesn’t necessarily mean that they’re that small, only in comparison to what we are familiar with,” she recalled.

Louise was discussing theories of life with a friend in English class when the subject of atoms was broached. The friend’s theory was that the solar system represents one atom of the billions which exist. Her friend hypothesized that this solar system is in someone’s body and all the atoms in our world are
actually solar systems with life in them. Despite the fantasy associated with this idea, Louise had been made to think about the concept of size, and she had realized that she knew very little about it at that time.

**Session IV: Individual**

**Session IV: 10-Point Questionnaire**

The questionnaire consisted of 10 questions which dealt with the metric system and measurement (see Appendix C). Six questions dealt with measurement and four referred to the microscope. Table 3 represents the percentage of questions participants answered correctly in each category.

Table 3

<table>
<thead>
<tr>
<th>Students</th>
<th>Measurement</th>
<th>Microscope</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bill</td>
<td>33%</td>
<td>100%</td>
</tr>
<tr>
<td>Frank</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td>Lauren</td>
<td>83%</td>
<td>50%</td>
</tr>
<tr>
<td>Louise</td>
<td>67%</td>
<td>25%</td>
</tr>
</tbody>
</table>

Each question on measurement and microscopy was chosen because it would have been introduced at some time during each participant's education. Everyone correctly answered the question dealing with the measurement of a one centimeter line. Three missed the question concerning the iris diaphragm which regulates the amount of light focused on the slide. Of the other five questions missed, three referred to the microscope and two referred to the metric system.
The students' scores for total correct answers on the questionnaire were as follows: Bill-20%, Frank-100%, Lauren-70%, and Louise-50%. For Bill, a senior, high school was four years in the past. As indicated by his autobiography, sports had been his focus in high school. Science had not been an important issue.

Each student had taken the science sequence of general science, biology, chemistry, and physics. Louise had also taken Biology II. Exposure to particular concepts without follow-up exercises to anchor these concepts may not have been meaningfully connected enough for students to recall the information. Table 4 indicates the correct answers given by each respondent.

**Session IV: Concept Map**

Coconstruction of the first concept maps proved to be very interesting (see Figures 5, 6, 7, & 8). The sessions were videotaped. Twelve terms were assigned for students to map. None had ever seen or heard of concept maps. Even after the procedure was thoroughly explained and they were given an example of a concept map, students still had difficulty connecting phrases between concepts. Further explanation was given, but no suggestions were offered, so as not to alter their ideas of how the concepts were connected. It was assumed that if their understanding of the concepts improved by the second mapping, comparing the two would provide a better assessment of their understanding.
Table 4

Students' Correct Questionnaire Responses

<table>
<thead>
<tr>
<th>Question</th>
<th>Bill</th>
<th>Frank</th>
<th>Lauren</th>
<th>Louise</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>1  The line at the end of this question is approximately how long?</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>100</td>
</tr>
<tr>
<td>2  The number of millimeters in a meter is:</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td>75</td>
</tr>
<tr>
<td>3  One nanometer is equal to</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td>75</td>
</tr>
<tr>
<td>4  The light microscope has the capability of measuring objects as small as:</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td></td>
<td>50</td>
</tr>
<tr>
<td>5  Which of the following represents the abbreviation of the nanometer?</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td></td>
<td>50</td>
</tr>
<tr>
<td>6  If an organism has been measured in millimeters, one must multiply by what number to convert to micrometers?</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td>75</td>
</tr>
<tr>
<td>7  The distance between the slide and objective is referred to as the:</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td></td>
<td>50</td>
</tr>
<tr>
<td>8  The smallest measurement in the following group of figures is the:</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td></td>
<td>50</td>
</tr>
<tr>
<td>9  The part of the microscope that regulates the amount of light passing from the light source through the specimen and through the lens system is the:</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td>25</td>
</tr>
<tr>
<td>10 The ability to distinguish detail in a specimen is called:</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td></td>
<td>50</td>
</tr>
</tbody>
</table>

Session IV: Concept Map and Session VII: Concept Map

Concept mapping was implemented as a strategy for research on the basis that the process would inform the researcher about participants' understanding of relationships between the concepts of size, measurement,
and scale. A microscope experiment was presented to students between the two mappings to see if their understanding of measurement and scale would improve. Ruiz-Primo and Shavelson (1997) "found that students can be trained to construct concept maps in a short period of time with limited practice" (p. 32).

The researcher chose to evaluate both coconstructed maps of each participant at this point in the results and discussion. Each student's maps will be placed with the discussion to simplify comparisons. Prior to each participants' mappings, the researcher gave an overview of the construction process of concept maps. She described the hierarchical arrangement of concepts from the most inclusive to the least inclusive. Novak and Gowin (1993) commented that it is not unusual for students to understand the meaning of new knowledge, but the authors added that the students may fail to integrate it meaningfully into their existing conceptual framework. Active cognitive thinking can be recognized on a concept map with an integrated, hierarchically arranged subject matter.

Various methods of analysis were applied to the concept maps. The researcher evaluated maps for the precision level of the linking words, the scientific validity of each proposition, and the gaps and misconceptions. Ruiz-Primo and Shavelson (1999) define a pair of nodes, or concepts, and the labeled line connecting them as a proposition. A proposition is the basic unit of meaning in a concept map (Novak, Mintzes, & Wandersee, 2000). It was a challenge for the researcher to make implications about how participants were thinking about concepts as participants had arranged concepts on the maps.
Participants' maps varied a great deal, both within their individual maps and between participants' maps. Each student responded to the task with varying degrees of frustration. This evaluation made triangulation with other data, relevant literature, and National Education Standards possible.

Novak and Gowin (1993) present two questions salient to concept map hierarchy, "We are constantly seeking to observe, [sic] What concepts do we know that are relevant? and What higher-order–lower-order concept relationships are salient to this topic of study?" (p. 98). The researcher did not suggest a hierarchical arrangement to the students. It was her desire, however, for at least one of the students to recognize the significance of scale as the superordinate, or key, concept during the process of data collection. The concept of scale was referred to at each step of the process. Alternate hierarchies were possible for representing the other concept relationships. The analogy of a "rubber map" (p.16) is used to refer to how relationships can be repositioned between subordinate and superordinate and to continue meaningful propositional relationships with other mapped concepts. This relationship was expected to occur with microscope parts and terminology. The terms "size," "measurement," "microscope," and "magnification" are subsumable to scale. The researcher's attempt to analyze why participants did not recognize scale as a superordinate concept will follow the analyses of participants' maps.
Bill's concept maps.

Bill had a difficult time with hierarchy, relationships, and connecting phrases. The entire process of concept mapping was a struggle for him. However, it was not possible to tell by his comments that he was having a difficult time. He appeared to be very confident. For each of Bill's concept maps (see Figure 5), the superordinate concept “microscope” was chosen. The researcher felt that this probably was a choice based on Bill's experiences. At the time of the first concept map, the microscopy experiment had not been mentioned. As each of the concepts were read, Bill chose the term with which he was most familiar. The researcher defined the terms “scale” and “resolution” for Bill. Even after the explanation, Bill placed them at the bottom of his first concept map. The researcher assumed Bill continued to find these terms difficult to understand. Scale was not recognized as a more complex concept than size. Bill assumed measurement to be a more general term because measurement is used in determining size and is addressed when applying scale.

Linking words to connect Bill's concepts were sparse on his first map. After the laboratory experiment, Bill's map revealed that the use of linking words continued to escape his understanding. Having been shown a sample map and an explanation prior to the process did not seem to help Bill in his search for linking words. On the second map, Bill used definitions for linking concepts. Linking words are considered to be “an essential aspect of instruction in
Figure 5. Bill's concept maps
Note: Student maps were recopied verbatim using computer-mapping software for greater legibility.
concept mapping” (Novak & Gowin, 1993, p. 34). It is the researcher's assumption that Bill lacked a clear understanding of the relatedness between several of the concepts, which added to his difficulty in assigning linking words.

Bill's second concept map indicated to the researcher that the intervening laboratory exercise had added to Bill's understanding of both the concepts and the mapping process. Even though linking is not definition, the researcher was pleased to see Bill's attempt to provide information indicating some knowledge of his understanding the concepts. Novak and Gowin (1993) originally had not used linking words because they had assumed anyone reading maps would be able to provide their own. With the realization that people were not able to make sense of the maps, Novak and Gowin began paying careful attention to the wording between concepts. There may be several ways for linking two concepts and it is possible that each could vary in connotation.

Bill's placement of scale below measurement indicates a gap in his understanding of scale. It appears that Bill relates scale with a numerical association. Perhaps he associated the term "scale" with an instrument for weighing such as those one would find for determining mass in a laboratory or perhaps even in a grocery store. This definition, of course, is not incorrect, but it is not the definition the researcher intended when used with micrographs or microscopy.

On Bill's second map, he clearly indicated an intervention had occurred prior to the mapping. However, arrangement of microscope parts were the only
significant changes. It was interesting that the first row of concepts under his key concept remained the same—"measurement," "field of view," and "magnification." Even though cross links were explained to Bill by the researcher, Bill did not use any cross links to indicate relationships between concepts on the same or different levels. The researcher assumes that Bill, instead of using a hierarchical arrangement, positioned concepts in an arrangement according to his understanding of them, or in some instances, his lack of understanding. Each map clearly indicated confusion about the mapping process and the concepts.

Frank's concept maps.

During the first concept-mapping session, Frank worked independently after the explanation, but his performance indicated a lack of understanding. From his hierarchical arrangement of terms (see Figure 6), the researcher assumed that his prior experiences had a significant amount of influence. In his autobiographies, Frank had recalled applying the concept of scale in a variety of circumstances, both in his daily life experiences and in his educational experiences. This information proved valuable to Frank as he easily structured his map.

Frank chose "microscope" as his key concept just as Bill had. Perhaps each of them had been influenced by the questionnaire, which had presented microscopy questions. On the first map, Frank placed "measurement" and "scale" in the same hierarchical position. The researcher attributes this to the way in which Frank had recalled terms when he wrote his autobiography. His
Figure 6. Frank's concept maps

Note: Student maps were recopied verbatim using computer-mapping software for greater legibility.
use of scale had always involved measurement. When Frank placed “magnification” below “scale” on the first map, the researcher was initially pleased. However, the linking words “need for” indicated a misunderstanding. Novak and Gowin (1998) refer to the ease “for students to be relatively passive and to relate new knowledge to what they already know in a imprecise fashion” (p. 98). Perhaps, this was Frank’s reason for having established many unexplainable propositions.

At this point in the study, because of Frank’s experiences mentioned in the autobiography and his correct answers on the questionnaire, the researcher anticipated that Frank would be able to assign meaningful linking words on the concept maps. Frank’s propositions of “size can be reduced to scale” and “scale need for magnification” seem to parallel recollections of how he first learned about relationships between the concepts. The researcher remembers that in his autobiographies, Frank had referred to attention he received in reference to his height and to experience he gained reading map scales when he was on vacation. These same examples from his autobiography could have been his reasoning for placing measurement and scale on the same level of hierarchy.

For linking “magnification” with microscope lenses, Frank chose “utilizes lenses of”. The lenses, “ocular,” “high power,” and “low power,” were placed at the same hierarchy and indicated that Frank knew that they were, indeed, for magnification. However, this left the term, “lens,” for him to place elsewhere in
the hierarchy. Frank’s placing the term at the bottom of the hierarchy was an indication that he had not gained a thorough grasp of hierarchical relationships.

Frank did not ask about what was meant by “resolution” as he was mapping. The definition of resolution he intended was that of clarity rather than the ability to reveal detail. With this misunderstanding, he was correct with his linking word “involves.” In this way Frank was correct with his proposition, “resolution involves lenses,” “field of view,” and “stage.” On his second map, Frank placed “resolution” below all lenses and “stage.” “Stage may have been placed here because, for clarity, adjusting the focus sometimes involves the movement of the stage. Frank did not have an understanding of resolution either before or after the laboratory experiment.

A misconception on the second map was evidenced by the proposition “size depends on field of view.” He could have been thinking about total magnification where one can figure the number of times a structure is magnified. Size can be determined, but it does not depend on the field of view. The second mapping came after the microscopy laboratory experiment. It is very difficult to explain how and why Frank arrived at some of the propositions. However, it must have had something to do with the laboratory experiment. The exercise involved determining the length of the field of view by measuring with a millimeter ruler. Students then had to count the number of _E. anacharis_ cells extending across the field of view and estimate the length of one cell. This use of the field of view with measurement may have been responsible for Frank’s associating size with field of view.
Frank may have connected "stage" with the lenses at the same hierarchy merely because he was at a loss to place it somewhere else. The only use of the stage, other than its being part of the microscope, was to support the slide of Elodea. "Stage" was also linked with the lenses, "high power," "low power," "lens," and "ocular," as the first part of a proposition, "increases resolution." Because it was part of a series, the researcher feels that Frank just connected it as he had the others.

**Lauren's concept maps.**

Lauren struggled with her initial concept map (see Figure 7), indicating partial misunderstanding with major errors. Her connections and hierarchy seemed to be influenced by some other kind of graphic representation where the organizing concept was centrally placed. According to the audiotape of the session and notes from this session, Lauren initially placed the superordinate concept centrally and had to begin another map that was more hierarchical.

Lauren exhibited more creativity than the other participants in the arrangement of concepts on her maps, especially her second one. Novak and Gowin (1993) note that "Creativity is often difficult to recognize, and even more difficult to illustrate to others. Substantial, novel integrative reconciliations are the major product of creative minds. . . .cross links can show novel concept integrations (at least to a student)" (p. 104). Just glancing at them, they appear to be complex.
includes Microscope can be Ocular
High Power Objective Low Power Objective

Concept Map I

Magnification is measured by Microscope
parts of Lens Ocular Stage
High Power Objective and Low Power Objective

Measurement includes Scale
depends on Resolution Field of View

determines

Concept Map II

Figure 7. Lauren’s concept maps
Note: Student maps were recopied verbatim using computer-mapping software for greater legibility.

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The superordinate concept on the first one was “measurement.” On the second one, “measurement” and “magnification” shared the superordinate position. The use of linking words was sparse on her first map and more complete on the second. Lauren was the only student to indicate direction with arrows between some of her concepts.

Why did Lauren begin her second map with “magnification is measurement” as the superordinate statement? The researcher can only suggest that the proposition was constructed as a result of measurement procedures conducted during the laboratory experience. The linking word, “is,” was incorrect. Lauren’s frustration may have played a factor in her poor choice.

Lauren was not pleased with the construction of either of her maps, but it appeared that she had enjoyed the process. On her first map, some of Lauren’s propositions about the microscope were correct and indicated that she recalled some of her experience with it correctly. The proposition that the “microscope depends on resolution” indicates unclear thinking. The connection between “microscope depends on resolution” and “field of view” indicates an eagerness to assign linking words, whether or not they are correct.

After the laboratory experiment, Lauren seemed to make more complex connections with cross links on her second map. She clearly stated that “magnification uses scale but does not alter size.” This proposition was realized at the end of the laboratory experiment by all participants except Frank, but only Lauren expressed it on her concept map. Novak and Gowin (1993) wrote “Cross links that show valid relationships between two distinct segments of the
On each map Lauren identifies the "lens" as "high power objective" and "low power objective." On both maps "ocular" is nearby but is not under "lens" as it should be. The researcher thinks that this is because of the location of the ocular's location at the top of the body tube of the microscope. Lack of experience constructing concept maps is the reason for this placement.

Another faulty association indicated on Lauren's second map is the proposition "magnification is measured by microscope." Total magnification is a figure determined by multiplying the magnification of the ocular lens times the magnification of the objective lens. Magnification is a factor by which an image is enlarged. Lauren has gaps in her thinking about how to express this connection of tool, "microscope," to process, "magnification."

"Scale" assumed a higher level on each of Lauren's maps in comparison to the other participants' maps, which demonstrates her meaningful conceptual understanding of scale. Roth (1990, p. 143) says that "Learning is not simply a process of adding knowledge into the head...but rather, learning is an active process in which the learner takes information from the environment and constructs personal interpretations and meanings" (cited in Mintzes, Wandersee and Novak, 1999). Mintzes, Wandersee and Novak (1999) expand this idea, asserting that language symbolizes "concepts, relations, and
modifiers," and that "these symbols are integrated to produce meaningful conceptual understanding" (p. 201). Thus "a person with conceptual understanding has an integrated picture of the whole structure, process, event, or other topic, rather than a disconnected list of fragmented ideas about its parts" (p. 202). Derry concludes that experts in a field "have richer, more interconnected semantic networks" (cited in Mintzes, Wandersee and Novak, 1999). While Lauren is not an expert, her second concept map indicates a greater complexity of linkages between key concepts, thus indicating a greater number of propositions; indeed, Lauren's second concept map was ranked highest of those of all participants, indicating a more thorough understanding of relationships.

Louise's concept maps.

Louise worked diligently until she completed the task. She seemed to understand the process and worked until she was satisfied with her map (see Figure 8).

Louise chose "measurement" as her superordinate concept for each map. On her first map "scale" was one of her first subordinate concepts and was placed on the same level as "field of view" and "size." With linking words "determinants of," the researcher would have assumed that the "field of view" Louise had in mind was not that of the microscope. However, the linking words of "determined by" to link "field of view" with "stage" indicated a partial understanding of microscope usage. There were definite gaps in Louise's memory of microscope usage.
Figure 8. Louise’s concept maps

Note: Student maps were recopied verbatim using computer-mapping software for greater legibility.
The second mapping revealed that Louise had remembered the connection of “field of view” to the microscope. Louise had a difficult time determining the correct linking words. This difficulty can be recognized by Louise’s use of “determinants,” “determined,” and “determine.”

Located on the third level of hierarchy of the first concept map, Louise placed “stage,” “magnification,” “high power objective,” and “low power objective.” These are all microscope parts which should have been placed below “microscope” hierarchically. The terms could also have been joined by cross links to show more understanding. There is little doubt by the researcher that Louise knew parts of the microscope. However, the hierarchical arrangement of concepts from general to specific was not fully grasped.

“Lens” and “ocular determine resolution” is a valid proposition. If Louise was able to make this connection, it seemed to the researcher that she could have drawn more cross links. Louise started over several times and seemed to take the mapping process seriously. The researcher noticed that Louise, as well as other participants, would mark off words on the sheet of paper as they positioned them on their concept maps. This may explain why some of them failed to return to the concepts and draw more cross links.

“Magnification created by microscope” was in no way linked to lenses or the ocular of the microscope. This is a significant statement indicating lack of precision in construction. Louise considered the microscope, not as the tool, but as the lens. Differentiating between the tool possessing the lens and the lens performing the action of magnifying was merely a poor choice of connections.
On her second map, Louise chose “using a” as linking words to form the proposition connecting “magnification” and “microscope.” This was significant improvement. The lab experiment had influenced a reorganization of the way Louise approached the concepts.

The propositions, “scale smaller objects high power objective” and “scale larger objects low power objective,” indicate only that Louise is aware of objective lens functions. Again the researcher would have liked to have seen cross links. Novak and Gowin (1993) write that evaluating “cross links that show valid relationships between two distinct segments of the concept hierarchy signal possibly important integrative reconciliations, and may therefore be better indicators of meaningful learning than are hierarchical levels” (p. 107).

Louise’s second map assumed a linear configuration. She said she recalled how to construct the map after I told her the assignment for the session. It was obviously a struggle for Louise to accomplish the task.

All parts of the microscope were placed in a subordinate position on the second concept map. Cross links were still missing on the map which, if drawn, could have indicated Louise had a greater depth of understanding of the microscope. Each of the concept maps drawn by Louise was very neat. Her emphasis on neatness may have interfered with proper organization of concepts. Louise presented neater maps on completion of the process than any of the participants.

Previous experiences with the concept of scale presented in her autobiography and interviews did not seem to help Louise recognize the
importance of this concept. During the first interview when she was asked to recall a reference to scale, Louise said, “I can’t remember. It’s been so long.” Continuing the questioning and asking Louise to think of reasons how understanding size, scale, and measurement would benefit her in the future, Louise responded:

Yes, of course. [It’s like Miss America being asked questions on the spot.] Well, you just need to know where you sit in this world—just to know. I don’t know any specific reasons besides that. I mean, you know, you’re not as small as some things and not as big as other things. But I don’t know how. I don’t know.

Louise is a mathematics education major. It was troublesome for the researcher to observe Louise’s struggles with relationships between concepts on her maps.

**Session V: Group**

**Session V: Video Presentation**

The video presentation where the students visually measured items with the scale bar and MicroMeasure™ system consisted of 20 projected micrographs. Result totals indicated performance equality between the scale bar and grid responses. Students were allotted as much time as they needed to estimate measurements and record answers. Total results, as shown in Table 5, indicated no overall difference in the two methods; however, students showed a lack of comprehension of scale when applying either method.
Table 5

Number of Incorrect Responses

<table>
<thead>
<tr>
<th>Student</th>
<th>Scale bar</th>
<th>Grid</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bill</td>
<td>5</td>
<td>6</td>
<td>11</td>
</tr>
<tr>
<td>Frank</td>
<td>5</td>
<td>3</td>
<td>8</td>
</tr>
<tr>
<td>Lauren</td>
<td>3</td>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td>Louise</td>
<td>2</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>Total</td>
<td>15</td>
<td>15</td>
<td>30</td>
</tr>
</tbody>
</table>

Session VI: Group

Session VI: Microscopy Experiment

After a review of how to use the microscope, students were presented a measurement task in which they had to make some connections between magnification and size by observing the aquatic plant *E. anacharis*. Measurement of the field of view was calculated with a small plastic 15 cm ruler. Upon completing measurement of the field of view, each student was instructed to draw a single cell viewed on low power and then again on high power.

The students had no trouble measuring the diameter of the field of view in millimeters (mm). Even the conversion from micrometers (μm) to mm did not bring hesitation. When they were asked to estimate the length of one cell in μm, however, they required some assistance from the researcher. The next task was for them to use their knowledge of scale to calculate the size of the same cell on high power. Frank was the only one who miscalculated. Bill,
Lauren, and Louise were aware that the measurement would be the same as it had been on low power.

Even though the initial interviews, questionnaires, videos, and autobiographies suggested gaps in prior experiences with concepts of size, measurement, and scale, when the students were actually applying the concepts in the laboratory experience, they demonstrated very little outward difficulty in their processing of information. Lazarowitz and Tamir (1994) confirmed that concept learning is significantly enhanced by laboratory experiences. They reported that the laboratory is a place for "identifying students' preconceptions, as well as a vehicle for extending or modifying such conceptions" (p. 99). Using the microscope, measuring the field of view, and determining the size of one cell on low and high power were no problem. Only Frank calculated the size of the cell on high power incorrectly. He realized his error immediately, however, when the researcher asked the students, collectively, what their answers were. He was astounded that he had made such a mistake. On his first concept map, he had indicated that scale needs magnification. On his second concept map, the subsumption of the concept "field of view" below "size," with the connecting words "depends on," suggests to the researcher that Frank had not resolved the misconception. Such misconceptions can be avoided with more precise information preceding microscopy-based activities.

Scale is a superordinate concept whose meaning becomes clearer with the understanding of subordinate concepts, such as size and measurement.
With the introduction of magnification, the complexity of scale assumes another dimension.

As magnification increases, students see the size of a microscopic image increase. This enlargement of objects or parts of objects in the field of view would be confusing to someone lacking prior size, measurement, and scale experiences. As the autobiography of each participant indicated, the latter experiences began early in their childhood.

**Session VII: Individual**

**Session VII: Electron Micrographs and Scale**

This session began with random positioning of three pictures each of parenchyma cells, leaf structures, open stomates, and statoliths (see Appendix F). Each of the three pictures depicted an alternate method of determining size—the MicroMeasure™ system, the Henkograph, and the scale bar. There was a consensus among the students that the grid diagrams of plants were the easiest to measure. The Henkograph was chosen as second and the scale bar, third. There was no hesitation on the part of any student when ranking these pictures.

It was interesting to observe the ease with which students responded to selecting the order of electron micrographs. All felt that if the MicroMeasure™ system of illustration were used in texts, then size and measurement of organisms would be more meaningful to the reader.
Session VII: Concept Map

Coconstruction of the second concept maps proceeded with less confusion than the students had experienced with drawing their first maps (see Figures 5, 6, 7, & 8). Bill remained puzzled about what linking words were, and he used defined terms instead. The hierarchy of Bill’s second map revealed more understanding of the terms than he had demonstrated on the first map but less understanding about the use of linking words. Both of Frank’s maps indicated some of his misunderstanding and demonstrated gaps in his awareness of the relationship of magnification to scale. Only Lauren created maps which made definite connections and which indicated clear understandings of concept relationships.

Louise had more difficulty making connections on the second concept map than on her previous map. (Her confusion may have been caused by a automobile accident she was involved in between the drawing of the Concept Map 1 & 2.) The second mapping resulted in a more linear arrangement than her previous map had. Prior to construction of the last map, Louise had been struck by a truck as she crossed a street in downtown Lake Charles. Even though she did not need hospitalization, she did receive some injuries requiring plastic surgery. This traumatic fact may explain why her second map did not show a significant improvement.

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**Session VIII: Individual Final Interviews**

**Session VIII: Informative**

Again, for ease in following student responses, the questions will precede the students' answers (see Appendix E).

1. Which of the sessions did you feel was the most beneficial in your understanding of the concepts of size, scale, and microscopy? In what way?

Three of the participants indicated that constructing the concept maps was a help in organizing thoughts about scale, measurement, and size.

Bill said that he found concept maps to be the most useful portion of the research for understanding concepts of size, scale, and microscopy. He commented that they helped him make connections better by forcing him to relate the concepts and that the maps helped him see differences and similarities among the concepts. Another helpful activity was writing his autobiography. Having to reflect on experiences he had in his earlier years made Bill think more deeply about the processes involving the key concepts.

Frank found that the measuring experience with *E. anacharis* microscopy had been his most memorable, helpful, and enjoyable activity. It prompted him to consider in more depth the concept of scale and its relationship to the field of view. He said that the procedure with *E. anacharis* had been very impressive. The researcher's perception was that he had really been surprised to be the only one who had not derived the correct answer for cell size when changing magnifications. His answer mirrored the researcher's perception:
I would have to say working with the microscopes and the Elodea. At first, I had to actually go home and think about it, and its like--. What actually happened, I knew the field of view. It didn't shrink because it always showed whatever the amount was, but I had to think about that in my head in that even though, you know, it looks like it's gotten larger, my estimate, in the beginning, was still the same. I'm just um-m, kinda zoomed in on it.

Lauren felt that the most beneficial session was the video because she was actually applying measurement to objects. She said that she liked it better when she was “actually doing something rather than being told about it.” This practice helped her realize “that magnification is important to size.” Her challenge to measure correctly the pollen grain, pin head, poppy seed, midvein, and louse had proven to be critically important.

Louise found the autobiography and the video to be equally helpful. The autobiography made her reflect upon her impressions of size as she was growing up. To apply scale to the video items was a real challenge for Louise because she did not “usually put to scale the little things.” She was evidently referring to the pollen grain, pin head, poppy seed, midvein, and louse which she had viewed on the video.

2. Can you think of other applications for the concept map technique that we utilized?

Bill suggested that a useful extension of mapping might be to relate it to strategies of basketball, suggesting he may import use of this tool to his personal life. Frank did not hesitate with his response when he was asked about other applications for the concept maps. He said that it could be used to see how other concepts work together. Lauren also recognized that there could
be many applications for concept maps. She responded that they could be used for analyzing “just about anything.” Louise thought that concept maps could be used by people who were interested in compartmentalizing information. She said that she had probably applied a similar technique when organizing presentations.

3. When we used the microscope, what was the most memorable activity?

All of the participants responded that their most memorable activity with the microscope was observing cyclosis in Elodea. Each enjoyed seeing the chloroplasts moving due to the cytoplasmic streaming (cyclosis).

4. Was there a particular procedure which you enjoyed performing with the microscope more than the others?

Bill, Frank, Lauren, and Louise reported that working with the microscope and E. anacharis were the events providing the most benefits in understanding size, scale, and microscopy. After the exercise Frank said that he had gone home thinking about the fact that even though the cells appear larger on high power, the structures remain the same size. Watching cyclosis and measuring the cells were interesting to Louise because she had not had the opportunity to use the microscope for a few years.

5. Did the coconstruction of the concept map help or hinder the process? In what way(s)?

Three participants appeared to have benefited from the coconstruction of the concept map. Bill had said initially in the interview that the concept maps
had helped him. He reiterated this and added that they had also helped him see similarities and differences in concepts more readily. Lauren insisted that the coconstruction of the concept maps had confused her and therefore had hindered her understanding of scale. She stated that she did not think in hierarchical terms. However, her second concept map indicated otherwise. When asked about the coconstruction of the concept maps, Louise admitted that at first she had been confused. Even though “it was not the easiest thing” that she had ever done, Louise said that she had learned from the experience. While Louise was aware of the value of concept maps for organizing learning, she said that it was difficult for her to think of other applications and asked for some examples.

Frank responded that at first he really had not understood how to construct a concept map, but that after the microscopy exercise, he found the second map much easier because he could make sense of the concepts, see how they related, and apply what he had learned. However, the researcher felt that the second concept map did not support Frank’s evaluation and that he needed additional exposure to the concept of scale.

6. Did you feel that the choice of activities was conducive to your learning the concept of scale? Which one was the most helpful?

All the students liked the choice of activities but had differing views about the most helpful. Bill chose the autobiography; Frank, the *E. anacharis* experiment; and Lauren and Louise, the video. Louise, in choosing the video as the most helpful in understanding the concept of scale, noted that using the
various methods of estimating the size of items was really different from using a ruler. This activity, Louise said, made her much more “aware of what the sizes of things are now.” She said when considering the concept of size hereafter, she will process the concept more thoroughly.

7. What impact will this activity have on the way that you view microscopy?

The participants differed in their estimation of the usefulness of microscopy. Bill and Frank did not think that the research would have much effect on how they view microscopy. Frank stated,

Well, since I’m not a science major, it didn’t have that much of an impact, but it did teach me an important lesson in that not everything that you see is actually what you think it may be. It may be something totally else—and just don’t assume. Try to sit down and figure it out scientifically, you know.

Lauren found the process had helped her realize the relationship that magnification has to size, and Louise said that she would definitely recall what we had done the next time she looked into a microscope. She said she would be much more aware of size.

8. Can you think of another method using microscopy that would enhance your understanding of scale?

The participants were consistently vague in suggesting other methods for enhancing their understanding of scale. Bill said more “hands-on” use of the microscope to enhance understanding concepts of the research project would be helpful. Frank, even though he could not think of specific examples, said that he was sure that “there are plenty of things that you could do to analyze
size and compare and contrast two things." Lauren could think of no other method involving the microscope that would enhance understanding of scale, but she said, "Um-m. I mean now I realize that magnification is important to size." Nor did Louise have any other suggestions for activities that would enhance her understanding of scale. She felt that we had done "about everything."

At the conclusion of each student's second interview, the researcher presented her/him with a check for the amount of time each had contributed to the research. Each student thanked the researcher and wished her well. It was the researcher's impression that the participants had each enjoyed the time she/he had dedicated to the project.

Data Interpretation

In order to give credibility to this project, the researcher chose to analyze the data via triangulation and to probe the students with multiple collection modes over an extended period of time. In addition, the researcher examined the data for specific patterns to emerge which would identify common themes as well as common misunderstandings which might arise from the four case studies.

The nine collection modes are listed chronologically in Table 6. The code for interpretation of the researcher's assessment of the nine probes varied from complete understanding to complete misunderstanding with three intervening levels of comprehension. Initially, each student was evaluated independently on her/his understanding of the key concepts of size, measurement, scale, and
Table 6

Categories of Student Understanding

<table>
<thead>
<tr>
<th>Student</th>
<th>Size</th>
<th>Measurement</th>
<th>Scale</th>
<th>Microscopy</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1 2 3 4 5 6 7 8 9</td>
<td>1 2 3 4 5 6 7 8 9</td>
<td>1 2 3 4 5 6 7 8 9</td>
<td>1 2 3 4 5 6 7 8 9</td>
</tr>
<tr>
<td>Bill</td>
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<td>C E X C E B A C C</td>
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<td>A A D D X A A B B</td>
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<td>Lauren</td>
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<td>Louise</td>
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<td>A C X B B A A D A</td>
<td>A A D D X A X B A</td>
</tr>
</tbody>
</table>

Codes for data types
1 = initial interview
2 = autobiography
3 = 10-point questionnaire
4 = initial concept map
5 = video presentation
6 = microscopy experiment
7 = electron micrographs
8 = final concept map
9 = final interview

Scale based on understanding
A = complete understanding
B = partial understanding with minor errors
C = no understanding (blank)
D = partial misunderstanding with major errors
E = complete misunderstanding (answers all incorrectly)
X = not applicable
microscopy. When considering all possible codes which could be assigned, the number totals 31/student. Out of these Lauren accumulated 28 As and Bs, indicating that she had complete or partial understanding with minor errors on most of the scored criteria. Frank and Louise each accumulated 25 As and Bs, whereas Bill accumulated only 14 As and Bs. Only Bill received a rating of a significant number of Cs (8/31) indicating that he had no idea on ~25% of the assessment items. Frank “scored” 6 Ds and Es, Louise 5 and Lauren 2 indicating that they had fewer misconceptions compared to Bill. Looking at these generalized results, the researcher predicted that Lauren would be the student who had demonstrated higher cognitive processes concerning the key concepts, Louise and Frank were close behind, and Bill had the greatest difficulty with them.

Although the researcher is aware that designing a scoring rubric for concept maps leads to more than one possible arrangement for propositions and cross links as well as hierarchies, an evaluation of the students’ concept maps had to be made in order to compare the results of these two activities with the other seven data collection modes. The researcher compared the results of the concept maps with the generalized results enumerated above. These results showed that out of 8 possible scoring items, Bill and Frank each earned 6 As and 2 Bs, whereas Lauren achieved 7 Bs (no As), and Louise 4 Bs (no As). What makes these results interesting is that the former two participants “outscored” the latter two, a reversal of the outcome when the generalized results using all 9 probes were tabulated.
The researcher then analyzed each of the 31 scoring items per student and tabulated the individual participants' rankings based on their understanding as indicated by the various codes which had been assigned. The student who was ranked the highest by the researcher was Frank, closely followed by Lauren, then Louise, and finally Bill. Ironically, although Frank scored the highest, he was the student who had the greatest difficulty with the microscopy experiment and the application of the concept of scale.

Table 7

Ranking* of Participants by Scores on Key Concepts

<table>
<thead>
<tr>
<th>Student</th>
<th>Size</th>
<th>Measurement</th>
<th>Scale</th>
<th>Microscopy</th>
<th>Overall Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bill</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>2</td>
<td>4th</td>
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<tr>
<td>Frank</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>1</td>
<td>1st</td>
</tr>
<tr>
<td>Lauren</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>3</td>
<td>2nd</td>
</tr>
<tr>
<td>Louise</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>4</td>
<td>3rd</td>
</tr>
</tbody>
</table>

*Values were obtained by analyses of Table 6 (Categories of Student Understanding).
CONCLUSIONS

Introduction

Relationships between meaningful learning, cognitive structure, and conceptual change are significant foci of educational research. Conclusions drawn from the data in this study will address these relationships. The student’s narrative of scale was the unit of analysis examined during each segment of the investigation. The four case studies generated data and provided information which were used to answer the metaquestions: How do selected introductory college biology students struggle to understand scale and measurement? How can this knowledge be enhanced if studied in conjunction with microscopy?

Information from the four students’ narratives of their experiences with scale provided data for the researcher as they revealed their prior experiential learning of microscopy, specifically, and relationships they had observed between scale, measurement, and size. The case studies revealed some general conclusions about undergraduate biology students’ struggles to understand scale and measurement and about their current precollege preparation for microscopy.

Results and Discussion of Metaquestions

By tracing the development of the participants’ knowledge about the concepts of scale and measurement throughout the case study, this research provided insight in addressing the metaquestions.
Among the first signs that participants did not clearly understand scale were their requests for a definition of the term *scale* as they were writing their autobiographies (see Appendix G). The question most often asked following the assignment was, "Exactly what do you mean?" After being given an example, students experienced no further problems completing their autobiographies.

In relating their prior knowledge of the concepts of size, measurement, and scale, students recalled few examples of experiences in the classroom. None of their examples were follow-up exercises that had been used to reinforce concepts or to introduce additional related information. Lauren and Louise mentioned measurement with a ruler in elementary school. The students' lack of recall was surprising. Perhaps the participants have not had much experience in reflection because of their youth.

These data support previous findings that many individuals use their bodies as prime referent for measurement. In the autobiography Bill described finding height an important measure, Frank remembered participation in preschool measurement activities, Lauren recalled learning the measure of 12 inches in elementary school, and Louise said she had recognized the complexity of measurement in third grade. An extreme comparison of size was Louise's association of atoms with the body—the notion, again, of the body as the prime referent for measurement. Did this "fantasy" result from oversimplification of the atom's structure depicted in biology textbooks? Some
textbooks instruct students that atoms are like little solar systems (i.e., the Bohr model of the atom). This explanation can create misconceptions unless carefully delimited.

- **Knowledge Enhanced if Studied in Conjunction with Microscopy**

  As activities were completed, students grew more confident in expressing their ideas. By the time the microscopy experiment was conducted, each participant seemed less apprehensive about approaching the activity (see Appendix I). After the researcher reviewed microscope usage, the students appeared relaxed during the remainder of the laboratory.

  Findings from the microscopy exercise indicate misconceptions can occur. Even though Frank had clearly indicated an understanding of scale on his concept map, his results were incorrect when he changed magnification. With more precise information preceding microscopy-based activities, student misconceptions may be prevented. This information should be introduced early in a student's education, prior to college entrance. Perhaps if misconceptions could be diminished at the high school level by more focused experiences with microscopy, students would relate the concepts of scale and measurement properly.

  In their final interviews, all students judged the *E. anacharis* experiment the most memorable activity using the microscope. These findings indicate the potential importance of using non-invasive, *in vivo* microscopy experiences such as *E. anacharis* cyclosis in motivating student curiosity. Earlier exposure
Research Subquestions

Examination of results provided meaningful data for answering the subquestions. These answers, which reinforce the metaquestions, focused on the influence of precollege science experiences, responses to three ways of representing scale on electron micrographs, and the mutual influence of scale and interpretation of electron micrographs.

- Influence of Precollege Science Experiences

The concept of size was, in some way, incorporated into the memory of each participant before entering school. According to the autobiographies size was manifested, without their knowledge, as a comparison to something that was larger than themselves. This concept is proportion and, ultimately, scale. Knowing that the origin of this idea begins early in life, educators have a foundation of information on which to build new concepts.

Louise's frozen, initial memory of size was that of a rocking horse: "I remember thinking it was huge, almost as big as a real horse." This vivid memory seems to indicate a need to address instruction on the concept of size of a class of objects at an early age, possibly preschool, and do it in an impressionable manner. It appears that early impressions are lasting ones.

Information from preschool through high school which related to measurement was sparse but had clearly been requested in soliciting the
autobiography of each student (see Appendix G). However, sparse as it was, the information indicated that precollege science experiences of participants lacked consistency in number and variety of activities relating to concepts of size and measurement. When thinking of biology, Lauren did not even realize the importance of measurement in biology except for its application to organismal size. Bill could not relate any schooling experiences to the concepts. Louise simply said she had measured planarians while working with them in biology. Only Frank seemed to be aware of the importance of scale and his awareness was due primarily to interaction of experiences at home and school. From the “walking ruler” in the second grade to his acknowledgment of using time, measurement, and scale in high school, Frank apparently had the most consistent experiences on which to base his knowledge of size, measurement, and scale. Had they just not recalled some of their experiences? After reviewing the students’ autobiographical information, the researcher believes this to be the case.

Findings seem to identify an existing perception that "time is more important than size" in our personal lives. This pattern of thought was expressed by all students in their autobiographies and in their interviews. This idea may negatively affect students in their struggle to understand scale and measurement. Could meaningful laboratory experiences in elementary school align these concepts for students? A positive experience could develop a student’s enthusiasm toward these concepts as the students mature. Time is
an essential measure in daily life and is becoming more so as the student matures. Comparisons of either structural movement such as the chloroplasts in *E. anacharis* or organismal movement such as protists to the student's own movement in a certain "field of view" may be an approach to explore in combining these two concepts for younger children.

The data do not seem to reflect any continuity on the part of educators in presenting memorable experiments which develop the concept of measurement or visualization skills aimed at fostering more curiosity in students. *Benchmark* (1993) recognizes the importance of these skills and advocates the use of magnifiers and rulers beginning at the kindergarten level. Bill and Louise recollected no experiences in elementary school relating to measurement. They probably had used rulers to measure, but they made no mention of any experiences. This failure was probably due to inconsistent exercises during earlier educational experiences rather than to their having had no experience at all. Better preservice mathematics education courses could improve conceptual understanding in teachers, resulting in their teaching measurement concepts in a more meaningful way.

According to Menon (1998) postgraduate preservice teachers of elementary school often have a procedural understanding of perimeter and area rather than a conceptual and relational understanding. His study involved 54 teachers. All had attained creditable mathematics scores in high school and preuniversity public examinations. Findings from four tasks implied the 54
teachers exhibited less than satisfactory performance in conceptual understanding. The investigators were concerned about the quality of teaching these preservice elementary teachers would present to the students in their classrooms. Perhaps the participants of the current study had encountered instruction which was more procedural than conceptual. This could account for gaps in student comprehension of concepts presented in this research.

Prior to Bolte's study, Reinke (1997) discovered similar findings about confusion on the measurement topics of area and perimeter. His subjects consisted of 76 preservice elementary teachers enrolled at a large university. Each had had a college algebra course prior to enrolling in the elementary mathematics content course. His results also indicated that the preservice teachers relied on procedural learning rather than conceptual understanding. It is important for students entering college to have developed critical thinking skills. Preservice teachers must have skills beyond those imparted to their students in order for them to develop those critical thinking skills.

Informed teachers are aware of technology available for extending student understanding of natural phenomena. An increasing amount of technology is available for associating the concepts of size, measurement, and scale. An example would be a computer program for students from grade nine to college reported by Johnson (1998) in A and P Technologist which depicts images of photographs and light and electron micrographs from research laboratories for synthesizing these concepts. In Benchmarks (1993), technology is designated as an integral part of a student's practical knowledge for solving
problems. The Scope-On-a-Rope could provide meaningful experiences for young people in K-12. Teachers have access to unlimited information about this instrument over the Internet. Any tools introduced to students in the classroom can increase their knowledge and expand their ideas about links between technology and science.

Hall (Carnevale, 2000), an associate professor of psychology, finds that technology is a tool for enhancement for teaching, either online or in the classroom. He believes that many professors are reluctant to replace their traditional lecture courses with computer instructional methods. Three advantages of computerized instruction are listed: (a) instruction based on student ability, (b) provision of multimedia to show simulation activities, and (c) collaboration of discussion groups. Hall also suggests that a reward system be developed for professors who develop and use technology in their classrooms.

An examination of the concept maps clearly shows that the sequence of the sessions helped the students gain insight about scale and measurement (see Figures 5, 6, 7, & 8). Bolte (1999) also found concept maps to be beneficial in the assessment of mathematical knowledge. What are the implications for education when a particular paradigm is found to promote learning? According to SFAA (1990) teachers will need a new slate of instructional tools to raise standards. Concept mapping is permeating textbooks to a greater extent now than in previous years, but how many classroom teachers actually realize the effectiveness of teaching students this technique? The National Science Foundation, textbook publishers, and companies...
producing audiovisual educational materials are committed to budgeting for the support of research to assist this reform.

- **Responses to Three Ways of Representing Scale on Electron Micrographs**

  The video which incorporates the scale bar and Henkograph indicates difficulty on the part of students in visually deriving the correct measurement of items. This was also true in the pilot study conducted by the researcher. Increasing the time frame for their estimations did not produce better results. However, when the students had hands-on experience in the microscopy experiment, they were successful in applying measurement skills.

  In session VII each student in the research examined micrographs that used three ways of representing scale (see Figures 5, 6, 7, & 8). Each student chose the same order for ease in estimating size: first the grid, next the Henkograph, and, last, the scale bar. Because there was a consensus in preferring the grid method of scaling micrographs, perhaps textbook publishers should examine the way micrographs are presented in textbooks. Are students presently being provided with the best representation of micrographs in a text if they have little concept of size? Is there a lack of attention on the part of educators informing students about the importance of photographs in textbooks? The scale bar is often overlooked or ignored. From data obtained in this study, gridlines appear to call attention to the micrograph and give students a better visual image of the actual size of magnified items. Results from the video presentation did not affirm these findings but the students' oral responses to the electron micrographs appeared to do so.
• Mutual Influence of Scale and Interpretation of Electron Micrographs

The concept maps indicate that the participants had an understanding of the concept of scale in that they had connected it to size, measurement, and magnification (see Appendix F). The linking words, however, indicate the connections were not adequately understood. Verbally, participants had expressed the relationship, but the mapping indicated they had difficulty in depicting a clear connection.

Both the written responses from the video of micrographs and the first concept map reveal the students' difficulties with the concept of scale. Results of the video presentation, with different magnifications of items, indicate that much more practice is needed before students attempt to determine size visually with the scale bar or Henkograph. The microscopy laboratory immediately followed the construction of the second concept map and in the laboratory students showed more ability with concept application. Following the laboratory session, students demonstrated confidence in placing micrographs in the same order.

Blystone and Dettling (1990) sampled research pertaining to textbook illustrations and present the idea of visual literacy as a skill. They suggest teacher involvement as the first step in improving the presentation of illustrations in texts. Results of this study agree with their conclusion. As teachers enhance student awareness of micrographs in texts by bridging size and measurement, students will be better prepared to deal with the concept of scale.
Data Summary

Based on the amount of information derived from the case studies, the researcher devised a scheme to triangulate the major findings of each segment of the research. The scheme will attempt to provide a "perfect fit" (Merriam, 1988, p. 143) between the research questions and the data. Tables were constructed according to participants, types of data, and participant understanding. Table 6 assesses categories of student understanding.

Knowledge and Value Claims

This research resulted in four case studies with support for the following knowledge claims:

1. Questionnaire responses were more positive toward the MicroMeasure™ system than the alternate methods of scale bar and Henkograph.

2. Students failed to connect their previous knowledge of scale to the video images depicted on the "Scope-On-a-Rope" video.

The case studies also support the following value claims:

1. The MicroMeasure™ system is more useful and understandable than the other two systems—the traditional scale bar and the Henkograph.

2. Students should relate the concept of scale to the concept of micrometry.

3. Textbooks should consider using the MicroMeasure™ system method of scaling micrographs.
4. Laboratories should spend more time developing the concept of scale.

Implications of This Study

While each student indicated some general knowledge of size and measurement, results of the concept maps, the questionnaires, and the video presentation indicate gaps or inconsistences in their mastery of these concepts. Since the information from the autobiographies indicates no lack of interest in size, the failure of participants to recall more significant examples of measurement and scale throughout their educational experiences is a problem that needs further investigation.

After meaningful preschool recollections of size and measurement, Bill, Lauren, and Louise reported sporadic contacts with the concepts in elementary school, a fact which could have influenced their difficulty in constructing the concept maps (see Figures 5, 6, 7, & 8). Frank's recall of specific examples of experiments, coupled with his perception that he understood the concepts as indicated in his autobiography, enabled him to approach the concept mapping technique more confidently than did other participants (see Figure 6). However, more emphasis on concepts rather than on procedures might have helped precollege instructors identify his misconceptions. Although Lauren's father had apparently encouraged her interests in science, she still avoided science after high school. Louise is a mathematics education major, but her concept maps indicate that she had some difficulty understanding the connection between scale and microscopy. It is not unusual for students to experience problems with initial attempts at concept mapping, according to Trowbridge and
Wandersee (1998). Becoming proficient with this process may involve making as many as 10 attempts. This was only the second attempt by Louise. Perhaps the students could have profited from constructing the second map cooperatively. This is a method that promotes science learning, according to White and Gunstone (1992). Interaction among the group would be more likely to clarify their ideas about the concepts and strengthen their areas of understanding.

The ease with which all but Frank arrived at the same conclusion as to the cell’s size is an indication that meaningful learning occurred. Frank said that he realized his mistake immediately when the others reported their answers. During the final interview, when Frank was asked if the coconstruction of the concept map helped or hindered the process, he replied,

Well, at first I didn’t really like understand it all. I just kinda like, well—I think this goes here, and this goes there. After using the microscope and making me think about it—about how the size of the object didn’t change and then going back and doing another concept map, I was like able to say, “Oh, now I know why this goes here and I can use what I had on the microscope.” I was able to form a better concept of you know, and be able to put things in order and how they related and apply what I had learned to it.

When his final map was drawn, however, the connections did not indicate that he understood the concept of scale in relation to microscopy.

The experiment with *E. anachariss* was one scaling experience where each of the students except Frank seemed to arrive at the correct conclusion at the same time (see Appendix I). All participants, including Frank, found this to be the most memorable part of the research. This group exercise was

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conducted three-fourths of the way through the process. These results indicate that students were beginning to understand scale at this point. Preceding exercises had enabled them to make connections as they switched from low power to high power and realized that the cell's size remained the same.

In the current *Louisiana Science Framework* (1997), one focus of curriculum development is stated as follows:

As investigations of the living environment are conducted, the rationales are set to establish further observation, measurements, and classifications of the various life forms. Patterns of similarities and differences within the diversity of life establish the basis for understanding the special relationships among living things in ecosystems. (p. 34)

This statement in the document precedes the benchmarks for grades K-4. Indications are that if this statement had been in the science standards during the early education of the four students involved in this research, these students would have been able to recall more elementary school examples of size and measurement in their autobiographies. Early awareness, which could involve experimentation comparable to the *E. anacharis* experiment, would provide more meaningful and memorable stimuli for elementary students. The *National Science Teachers Association (NESTA) Pathways to the Science Standards, Elementary School Edition* (1997) states, when referring to K-12 Unifying Concepts and Processes, “that the meaning of measurement and how to use measurement tools are a natural part of any investigation” (p. 29). Measurement is a vital component of science and, with proper development of
this skill, students will likely become more cognizant of its relationship to other
disciplines.

The importance of this research on student understanding of scale is
indicated by the prevalence of this key concept in Benchmarks and other
science standards as developed by various national science organizations and
boards. Scale is one of the four common themes which pervades science,
according to the AAAS in Science for All Americans (1990). The importance of
an understanding of scale to students in grade levels kindergarten through
twelve (K-12) is recognized by the National Research Council (NRC, 1996) in
the National Science Education Standards as essential. AAAS is making its
contribution to a national reform movement through Project 2061 (1993) in an
effort to make science literacy a goal for all Americans.

Literature references are plentiful on the need for students to understand
microscopy. The American Biology Teacher has few issues without one or
more references to microorganisms or microstructures. Dubowsky (1996)
stresses the use of the microscope to enhance the understanding of the
concept of scale in the classroom. AAAS also recommends the microscope as
a useful instrument in the learning of scale. Gowin (1981) provides support for
this possibility when he states, “A laboratory science is an appropriate place for
students to undergo experiences such that regularities are tied to concepts” (p.
144).

The importance of microscopy in learning measurement should not be
underrated. According to Hendee and Wells in The Perception of Visual

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Information (1997), some of the most creative scientists and cognitive specialists continue to unravel the mystery of how we see and how we know what we see. As the public becomes more dependent on decisions which are based on the interpretation of visual information, educators realize the need for students to be knowledgeable about the presentation and interpretation of visual information. Activities for the participants in this research addressed these concerns. The research clearly indicates that educators should also address these concerns in laboratory activities.

The video presentation, microscopy experiment with Elodea, concept maps, and electron micrographs each assessed visualization skills necessary for students to gain confidence with scale and measurement. The results of both the video presentation and concept maps indicate that students have difficulty in size estimation and measurement. The microscopy experiment suggests students can apply concepts and arrive at correct conclusions if they are active participants in their learning.

Participants indicated in their autobiographical accounts, interview answers, and video responses that the concept of scale had not been adequately developed in their educational experiences. Yet, after the laboratory experiment, Bill, Lauren, and Louise realized the cells of E. anacharis were the same size whether on low or high power. These connections were made simply by synthesis, and observation of their experiences in laboratory indicated meaningful discovery learning had taken place. Introductory laboratories need to stress experiments similar to the microscopy exercise conducted by the
participants to develop and/or reinforce the understanding and interconnectedness of the concepts addressed in this research.

Novak (1998) reaffirms meaningful learning, a significant concept of Ausubel's cognitive assimilation theory, when he wrote "For Ausubel, meaningful learning is the nonarbitrary, nonverbatim, substantive incorporation of new ideas into a learner's framework of knowledge (or cognitive structure)" (p. 39). The three criteria for students to be able to acquire meaningful learning are (a) it must have meaning, (b) it must be relevant to other concepts already possessed by the learner, and (c) the learner must want to attain the knowledge. Rote learning refers to concepts developed without strong hierarchical frameworks. These arbitrary, unanchored propositions can interfere with the acquisition of new information. The researcher identifies the problem Frank experienced in his measurement of the cell as such a faulty concept. The resulting mistakes in Frank's concept map support the influence of science laboratory experiences in enhancing concept learning and in developing reasoning skills as reported by Lazarowitz and Tamir (1994). When laboratory activities also identify misconceptions, laboratory can be effective in "diagnosing and affecting conceptual change" (p. 99).

Mintzes, Wandersee, and Novak (1999) recognize assessment of student learning as an important component for determining high-quality education. The concept map was an integral part of investigating the participants' cognition of concepts in this study. Many schools, colleges, and universities have adopted the concept map as an instructional tool. An
invaluable outcome of this project would be to study how to make all educational facilities aware of various alternative assessment tools such as concept mapping and how to effectively incorporate them into the classroom.

It is possible that the small set of volunteers did not adequately supply the researcher with representative thoughts and experiences of their peer group. However, the findings do support the data many other researchers have encountered (Ausubel et al, 1978; Blystone and Dettling, 1990; Menon, 1998; and Mintzes et al., 1999). In addition, there are implications for future study generated by the data. Despite the limitations of this study, however, the researcher has identified several informative findings. Student enrichment through additional microscopy experiences will expand their understanding of size, measurement, and scale. Real-world applications of these concepts would provide the background students need to formulate their own cognitive ideas.

Mintzes, Wandersee and Novak (1997) stress "the significance of cognitive processes and the role of prior knowledge in the personal construction of new knowledge" (p. 53). The well-known learning principle first iterated by David Ausubel reminds us that "The most important single factor influencing learning is what the learner already knows. Ascertain this and teach him accordingly" (1968 [2nd ed. 1978]).

In conclusion, since it appears that students entering college may lack skills relating to size and measurement, this study seems to indicate that microscopy instruction needs to address college biology students' existing
concepts of size, scale, and measurement. This link, instruments to
measurement, is affirmed by Wilson (1995):

Science differs from natural philosophy not simply and perhaps not
primarily in its attention to quantification, but in its use of instruments
both for measurement and for the creation of artificial states and
experiences. Measurement and computation are robust practices that
link ancient astronomy with every modern scientific branch of inquiry. (p.
70)

Another finding which appears to be supported by this research is that
since it is difficult to alter first impressions, the initial instruction about the size
of a class of objects must be done correctly the first time. This study also
revealed that students often mask their struggles with these concepts unless
instructors anticipate them and know how to reveal them. Yet another finding
which emerged from this study was the importance of the MicroMeasure™
system to visualization of the concept of scale.

The capacity of microscopy experiences to enhance the developmental
process for integrating size and measurement with scale in early grades needs
to be further explored. An investigation assessing differences between
introductory college biology majors and non-majors in their perceptions of scale
and measurement would be beneficial in establishing which precollege
experiences were the most effective. Future large-scale studies involving
students with varying backgrounds from different geographical areas are
needed to substantiate the findings of this study.
REFERENCES


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APPENDIX A: VIDEO: STUDENT RESPONSE SHEET

Age Group (Please check one.)
Elementary School [ ]
Junior High School [ ]

Answer Sheet for Video Presentation

Answer the questions by filling in the blank with the most appropriate answer. Place the letter only in the space provided for the answer which most nearly describes the measurement of the item.

   a. 0 - 0.5 mm   c. 1.1 - 1.5 mm   e. 2.1 mm +
   b. 0.6 - 1.0 mm  d. 1.6 - 2.0 mm

Example: (1)_____  (3)_____  (2)_____  (4)_____

1. _____          11. _____
2. _____          12. _____
3. _____          13. _____
4. _____          14. _____
5. _____          15. _____
6. _____          16. _____
7. _____          17. _____
8. _____          18. _____
9. _____          19. _____
10. _____         20. _____
APPENDIX B: STUDENT CONSENT LETTER

Date ______
Dear ______________________

Presently, I am researching how students learn microscopy and relate it to size and measurement. You have consented to be a participant in my study and for that consent, I wish to thank you. This letter is to inform you of the specific nature of the dissertation and also to help you understand your role.

My investigation will attempt to establish how well the science courses are fulfilling their responsibility in teaching the concept of scale as it has been established by organizations such as the American Association for the Advancement of Science (AAAS). The project was begun in 1985 in an effort to reform K-12 education in natural and social science, mathematics, and technology. Questions to aid in this endeavor are:

(1) How do college biology students respond to three ways of representing scale on electron micrographs?
(2) How do precollege science experiences influence the undergraduate biology student’s concept of scale?
(3) How does the college biology student’s concept of scale mutually influence the student’s interpretation of electron micrographs?

There will be four group sessions and four individual sessions each of which should last no more than one to one and one-half hours. You will be compensated the U.S. minimum wage ($5.15), for your time. Meetings will be set to accommodate your schedule. Data will not be shared without your permission. There will be no way for anyone to identify you personally because the name and identifying traits will be changed.

You will receive a copy of this letter. If you have further concerns, please feel free to discuss them with me, Juliana Hinton (home: 478-8138, McNeese State University: 475-5651) or my major professor, Dr. James H. Wandersee (Louisiana State University: 504-388-6867).

You may discontinue your participation in this project at any time without penalty. If you desire information addressing your rights as a research participant, please feel free to contact the Office of Research Services, McNeese State University, 475-5394.

Thank you for participating

Juliana Hinton
Doctoral Candidate, Science Education
Louisiana State University
APPENDIX C: 10-POINT MICROSCOPY QUESTIONNAIRE

Questionnaire

Please read each of the questions very carefully and answer them to the best of your ability. This is not a test that will in any way influence your grade. It is merely a tool for me to know how knowledgeable you are about this information at this time.

1. The line at the end of this question is approximately how long? _____
   a. one millimeter (mm)   d. one nanometer
   b. one centimeter (cm)  e. one inch
   c. one micrometer (μm)

2. The number of millimeters in a meter is:
   a. one tenth (0.1)  d. one hundred
   b. one hundredth (0.01)  e. one thousand
   c. one thousandth (0.001)

3. One nanometer is equal to:
   a. 10 meters  d. one thousandth millimeter
   b. 10^{-3}  e. 10^{-9} meters
   c. 10^{-4} meters

4. The light microscope has the capability of measuring objects as small as:
   a. 0.1 μm  c. 0.1 mm  e. 1.0 cm
   b. 0.1 mm  d. 0.1 cm

5. Which of the following represents the abbreviation of the nanometer?
   a. mm  c. nn  e. cm
   b. μm  d. nm

6. If an organism has been measured in millimeters, one must multiply by what number to convert it to micrometers?
   a. 0.1  c. 100  e. 10,000
   b. 0.01  d. 1,000

7. The distance between the slide and the objective is referred to as the:
   a. field of view  d. depth of field
   b. working distance  e. diameter of field
   c. focal plane

8. The smallest measurement in the following group of figures is the:
   a. nanometer  c. decameter  e. micrometer
   b. millimeter  d. centimeter

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9. The part of the microscope that regulates the amount of light passing from the light source through the specimen and through the lens system is the:
   a. aperture c. condenser e. stage micrometer
   b. diaphragm d. ocular micrometer

10. The ability to distinguish detail in a specimen is called:
    a. resolution d. image clarification
    b. par focal adjustment e. focus ability
    c. contrast orientation
APPENDIX D: INITIAL INTERVIEW QUESTIONS AND RESPONSES

INITIAL INTERVIEW WITH ______________ DATE ______________
CONDUCTED BY JULIANA HINTON McNEESE STATE UNIVERSITY

1. What is your student classification and major?

2. Could you please tell me about your background in science.

3. What activity did you enjoy most in science?

4. What was your earliest experience relating to the size of something in your environment?

5. As you got older, did your impression of this experience change?

6. Do you remember your first school task where magnification was involved?

7. Was there anything special about the task that made it memorable?

8. Prior to high school were there references to size comparison or scale that you recall? What were they?
9. Did you have a “hands-on” experience with the microscope in high school? (If so, ask: In what course was it? Did you have instructions before using the microscope?)

10. Were you ever asked to do a measurement exercise with the microscope? (If so, ask: What instrument was used in measuring?)

11. Can you think of any reason that the understanding of size, scale, and measurement would benefit you in your future?
INITIAL INTERVIEW WITH BILL
BIOLOGY STUDENT
CONDUCTED BY JULIANA HINTON
(TAPE TRANSCRIPTION)

JULIANA: What is your student classification and major?

BILL: I am currently a senior and my major is mass communications.

J: Could you please tell me about your background in science.

B: That's a good question. My background in science. My background is basically what I learned in school basically. I mean, it's not like I go outside of school to try to learn more about science and biology and all that. I mean–

J: O.K. Uh, where did you go to school and what sciences have you had?

B: In high school I took biology, I took chemistry, and physical science. In college, I went to Tulane University—that's in New Orleans, LA. I took biology over there and I took biology lab and I came here to McNeese State. And I took 101 Biology and I took a lab and now I'm taking 101 again, so—geology—I took geology, too.

J: What activity did you enjoy most in science?

B: Dissecting frogs and stuff like that. That was pretty fun. That's what I remember most about biology.

J: What was your earliest experience relating to the size of something in your environment?

B: I don't understand the question.

J: O.K. Let me let you look at them while I ask them. What do you recall, earliest in your memory, that made you think about size in your environment where you were growing up?

B: What do you mean—size? You mean uh–

J: Size, relationship to measurement.

B: Measurement?

J: How you felt about the size of something when you were real young.
B: When I was young, all I cared about was dealing with sports like basketball—basketball goal, ya' know because it was—was ten feet you know and uh I wanted to know how high the rim really and at the time I really wanted to know. And at the time, it seemed like the furthest away when you're small and you're trying to school this ball into a goal so that's when I—that was the first thing that came to me when I started thinking about size.

J: O.K. As you got older, did your impression of this experience change?

B: Definitely. The goal seemed like it was getting closer and closer to me, you know, the taller I got, it's like the smaller the distance got.

J: Do you remember your first school task where magnification was involved?

B: Ha, ha! Magnification was involved. I guess it would have to be in high school. Uh, dealing with the microscope. Uh—

J: Magnification—anything being enlarged.

B: The only thing I can remember is like using the microscope and putting something under the microscope. You know, like a plant or a frog or like-like pieces of, you know, like different elements that you find, you know. Hey, it's hard to remember. But, you know, it's the first time I used it. I think the first thing I saw had to be something dealing with the frog.

J: In the tenth grade?

B: Yes, exactly. That was like the biggest experience for me—when it comes to biology.

J: Was there something about that particular task that made it memorable?

B: Hm-m, that it was science. That I was a scientist, for a minute.

J: Good, that's good. Prior to high school were there references to size comparison or scale that you recall?

B: Another one of those questions I don't quite understand.

J: O.K. Where you had to think about the size of a particular measurement in relationship to another comparative structure.
B: These are some good questions, ya know. Ha, ha. That's a long time ago.

J: O.K. You know, like the scale on a map.

B: Right.

J: Were there any references that you can recall from your educational experience before you got to high school where you had to compare the size of something to a particular size designation, maybe?

B: Funny you should use a map. The only thing I can think of is like I was from Louisiana so we had to compare the size of Louisiana and Texas, you know—the size of it. And I guess when I was little, I couldn't figure how one state could be so small and the other one could be so big. You know, why couldn't they make them all even. You know.

J: O.K.

B: That was interesting.

J: So you've described the hands-on experience that you had with the microscope in high school and said that it was biology. Did you have instructions prior to that using the microscope—or even at that time? Did you have instructions on how to use the microscope?

B: Yes, oh, uh, like—I want to say a week—but I know it was a couple days before we would go over different things that you would have to do before using a microscope, and then it's like—like—they're expensive and he didn't want us to break them or anything like that. So he was trying to give us a heads-up on everything that ya need to know before you actually get to use it so it won't break.

J: O.K. Were you ever asked to do a measurement exercise with the microscope?

B: Measurement? Yes. You mean like putting something under it and measure it to see—to compare different specimens or something like that?

J: Yes.

B: Yeah, we had to do that.

J: And you were using the microscope?
B: Yes.

J: Can you think of any reason that the understanding of--size, scale, and measurement would benefit you in your future? (Repeated.)

B: I can think of a couple. You say scale, measurement--

J: And size--

B: This might not be what you think it is--but uh, for me--I'm trying to play basketball, so for me like weight and how much I weigh and like, it allows me to determine like how fast I can go, plus my quickness, it's like I gotta be a certain weight so I can move a certain speed and if I want to put on some muscles well that's mass or get some more beef on you. That didn't answer your question.

J: No, it did. It definitely does. And that is definitely going to affect you in the future. Are there any others? So that's size in relationship to your muscle structure.

B: The question? Measurement--that comes into play--I have to, uh, my jumping. I have to see how much--how often do I have to workout to jump as high as I want to jump--to be able to dunk the ball or make a lay-up or something like that if I have a seven footer in front of me or something like that. Ya' know measurement comes into play there because like ya' gotta work out a certain amount of time. Like say--if I have a thirty-five inch vertical mount, I would want the forty inch vertical, so I would have to do certain things that would help my jumping ability. Ya' know. So that all ties in with getting more muscles in certain areas--concentrating on working on certain parts of the legs and certain parts of the stomach muscles. Stuff like that. That's where measurement comes into play.

J: O.K., Bill.

B: Scale? I don't understand scale.

J: Well, in a way, you're using that now, when you talk about the distance you want to jump in order to get above a certain height. So that's a comparison using scale. O.K., Bill. I want to thank you for your time. I really appreciate it and until our next meeting--I'll see ya' later!
JULIANA: This the initial interview with Frank. What is your student classification and major?


J: Could you please tell me about your background in science.

F: Science as in high school science. I had four years of science. In the freshman year I took general science, sophomore year I had biology, junior year I had chemistry, and senior year I had physics.

J: What activity did you enjoy most in science?

F: I liked physics a lot. Most people don’t but just because of the math and like doing formulas and stuff like that. It’s probably my favorite.

J: What was your earliest experience relating to the size of something in your environment?

F: Could you kinda go into more detail on that?

J: Sure. Just as a young person growing up, can you think of some memorable experience that you had with something concerning the size of anything that you can think of.

F: Like when I was smaller?

J: Yes, exactly.

F: Maybe like my parents’ shoes or something like that? You know. Just how small my foot was compared to theirs. Just kinda clothing like stuff—as relation to my own.

J: O.K. As you got older, did your impression of this experience change?

F: Well, as I got older, I got bigger so—and right now bigger than both my parents—so it does.
J: Do you remember your first school task where magnification was involved?
F: Magnification like?
J: Of an object increasing in size with some type of lens.
F: I think maybe in the fourth or fifth grade like our science teacher would use like maybe magnifying glasses and I remember one time like prisms made like, you know, the rainbow and stuff like that so something to do with magnification.
J: Was there anything special about the task that made it memorable?
F: Special? Just we got to go outside and do stuff with magnifying glasses.
J: Prior to high school were there references to size comparison or scale that you recall?
F: I'm trying to think like in junior high school and stuff like that like map scales, I don't ever remember working with microscopes, some kind of strong magnification like that until I got to high school. But definitely, like you know, depth and stuff like that like either in social studies or sometimes in like science but not like on an impressionable level I guess you'd say.
J: Did you have a “hands-on” experience with the microscope in high school?
F: Uh, yes.
J: In what course was it?
F: Probably, maybe even in environmental-general science, but I definitely remember it in biology that I used it.
J: Did you have instructions before you used the microscope?
F: Uh, the teacher explained it. We went over it in class. Like I do, I remember, you know, diagramming the microscope—having to know all the parts of it.
J: Were you ever asked to do a measurement exercise with the microscope?
F: Um, not that I can remember. Only thing that we did was like we just observed stuff under the microscope. Uh, measurement, if you mean like magnification wise—like determining how much magnification?

J: No, the size of the object you were viewing.

F: Um, I, I can’t—I don’t think so.

J: Can you think of any reason that the understanding of size, scale, and measurement would benefit you in your future?

F: Um, not really. It’s just, I guess, one of those things that you need to learn how to do. And do stuff like that. I know like even helping my dad out, like helping him with the car. You know its like he needs a 16 millimeter wrench. You know I have to know exactly what they look like. Sometimes I have to just look at it and guess what size wrench it is. But um, I didn’t, I don’t think it was emphasized like, we’re setting up measurement now. Um, obviously I was taught the metric system, the English system and I knew how to do that. But probably as relevant to my own size and my own kinda place, I guess its just kinda there. Wasn’t really pointed to it I guess you’d say.

J: It’s more like something that was taken for granted?

F: Kinda, maybe taken for granted. Um, just like it’s there and I guess you thought about it—yeah, oh well. It’s so small compared to like something else. Like in comparison. Didn’t do a whole lotta that—I can’t remember. But it was just kinda basically teaching you about what this is, what does it do, how is it relevant? Not so much the size of it.

J: You can think of no other reasons, perhaps in the future, that these concepts might be even more beneficial? I’ll give you a little extra time to think about that.

F: So that’d be like—?

J: Size, scale, or measurement. How it would benefit you to understand these concepts later in life.

F: Well, maybe not from a scientific viewpoint just because that’s not my major but like it’s you know, um, like just measurement itself, you know. Understanding like how far something away is, you know, how do I relate that to my life, you know, like realizing that I have to plan this out because of time wise like how far to drive and how long you know how
small something is. Like if you're reading a map, you know oh well you have the whole state of Texas there. Well, you know, this means so much and stuff like that. I can see how that could be beneficial.

J: O.K., Frank, I want to thank you very much for your time. I appreciate your comments and I look forward to our next session.

J: Frank is giving me another example that he got from Middle School. Go ahead.

F: Well, it was actually the freshman year of high school in environmental science and what we were doing is we were studying about the planets and our teacher gave us ten oranges and she had a piece of construction paper and we had to measure how far apart things were—like beginning at the end of the hallway we had the sun and then so however many meters or centimeters we placed the planet Mercury down the hall. It was to scale. It was fun to see how you had the sun at the end of the hallway and the maybe ten meters away you had Pluto all by itself and then that way you could get a relevancy of how the planets were shaped, obviously on a much smaller scale. But you could see how far it was away from the sun.

J: O.K., very good. Thank you!
INITIAL INTERVIEW WITH LAUREN
BIOLOGY STUDENT
CONDUCTED BY JULIANA HINTON
(TAPE TRANSCRIPTION)

JULIANA: What is your student classification and major?
LAUREN: I am a freshman and I am majoring in Mass communications.

J: Could you please tell me about your background in science.
L: Well, uh, I took science in high school and I took biology I and physical science, physics and chemistry. And that--

J: What activity did you enjoy most in science?
L: Um-m, I guess, as far as, in general. My dad is an anesthetist and during dinner sometimes, he would talk about operations and whatever, and that was always really interesting to me just when he would talk about the human body and stuff like that when we were eating.

J: What was your earliest experience relating to the size of something in your environment.
L: I have no idea.

J: O.K. Think back as far as you can about your first impression of something of size—the size of something in relationship to perhaps your size.

L: Well, the only thing I can think of right now, in kindergarten, the teacher was trying to teach us the difference between whole and half, and she was breaking graham crackers in half.

J: O.K. What about the way you felt as—your body in relation to the size of something in your environment.
L: I don't know. I don't think I ever really thought about that.

J: O.K. Fine. As you got older did your impression of the graham cracker experience change—the half and the whole?
L: Well, no not really. It meant—you know—I know what half and whole is now. I guess as far as, you know, my relationship to size I think about things, you know. I've been to New York, and you see the Empire State
building, and it's humongous, and, you know, you just kinda wonder how many people standing on top of each other it would take to be that high up. I don't know.

J: O.K. That's exactly what I wanted you to think about.

L: O.K.

J: Do you remember your first school test where magnification was involved?

L: I remember looking at stuff under the—what was it? Yeah. We looked at cork cells under the microscope in like sixth grade—dyed with, with iodine. Right?

J: Well, perhaps they used a stain. Was there anything special about the test that made it memorable?

L: Well, other than that, it was my first time. I don't think there was anything particularly special.

J: O.K. It was your first time to use the microscope?

L: Yeah.

J: O.K. Prior to high school were there references to size comparison or scale that you recall?

L: Well, uh-h, yes, there were. There was the metric system versus the system that we use—

J: English.

L: Yeah. And I remember wondering in junior high why we didn't use the metric system. And then trying to figure out how I could change that.

J: You preferred one over the other?

L: Well, yeah. The metric system is like in tens. It's just easier instead of like twelves and 24 and 3.

J: O.K. Good. Did you have a hands-on experience with the microscope in high school?

L: Yeah.
J: O.K. What course was it in?

L: Uh-h. Must have been biology.

J: Did you have instructions before you used the microscope?

L: We had a test on the different parts of the microscope and how to use it. Yeah, definitely.

J: Were you ever asked to do a measurement exercise with the microscope?

L: Um-m, I'm not exactly sure. The only think I can ever think of as far as measurement and the microscope is that there was a certain lens for looking at something—looking at it at different magnifications.

J: Very good. Can you think of any reason that the understanding of size, scale, and measurement would benefit you in the future—in your future?

L: In my future?

J: Uh-huh.

K: Uh-h, other than general knowledge—. You know, I guess the understanding of size, scale, and measurement would, you know, provide a general understanding of things. I mean, I'm gonna be probably a journalist or writer, so I'd kinda have to know something about how big things are—you know.

J: Uh-huh. O.K. Thank you very much, Lauren.
JULIANA: Louise, what is your student classification and major?

LOUISE: I will be a junior, and my major is education.

J: Could you please tell me about your background in science?

L: In high school I had Physics, Chemistry, Biology I, Biology II, but I haven't had any sciences since high school, and, uh, 'til now.

J: What activity did you enjoy most in science?

L: Definitely, uh, oh, gosh—I'm terrible on tape. Oh, dissecting the pig our sophomore year in biology. That was fun.

J: Very good.

L: Interesting—very interesting!

J: What was your earliest experience relating to the size of something in your environment? (Pause.) Your earliest experience.

L: Like?

J: Like your size in relationship to something.

L: Oh, gosh. I don't understand. Like what do you--

J: Like when you thought about how large something was when you were real little.

L: Living on the lake—I guess that's gotta be it. I thought that was the biggest thing in the whole world. I could see New York from the wharf. Ha, ha.

J: Good, good. O.K. As you got older, did your impression of this experience change?

L: Definitely. I realized it was not New York—it was industries, and the lake's a lot smaller than I thought it was.
J: Well, that's good. Do you remember your first school task where magnification was involved?

L: No, but I remember in high school looking through major microscopes for the first time. That was cool. Light microscopes and looking at bacteria and stuff like that. I remember that.

J: You don't remember anything earlier in elementary school, in junior high?

L: No.

J: Having something magnified larger than its actual size?

L: No, I don't remember. That's terrible!

J: No, that's all right.

L: I have a terrible memory.

J: No, that's O.K. Was there anything special about the task that made it memorable?

L: Well, the most fun one that we did was—we had these little paramecia? And we'd raised them—we cut them in two.

J: Planarians—flatworms!

L: That was—besides looking at hair underneath the microscope—all that stuff like the first few times—that was, um, our first major thing that we had to do with the microscope, and we had so much fun. We named 'em, we cut 'em in two, we raised them,—we had to do all that stuff. It was fun.

J: Very good. Prior to high school were there references to size, comparison, or scale that you recall? Size, comparison, or scale—you know, a comparative measurement.

L: Like with—with the—

J: Anything, anything—in math or geometry prior to high school.

L: Um-m—
J: The scale of something where you're taking one measurement and comparing it to the size of something else.
L: I can't remember. It's been so long.
J: That's all right. Did you have a hands-on experience with the microscope in high school? You said you did.
L: Yes, definitely.
J: And it was in biology?
L: Biology—and we did it in chemistry and physics—and the ones I remember the most are in biology.
J: Did you have instruction on microscope use prior to the exercise?
L: Yes.
J: Were you ever asked to do a measurement exercise involving the microscope?
L: Yes. I don't remember, but I remember having a little special ruler and having to measure the length of a planarian.
J: Planaria?
L: Yeah.
J: So you used a ruler?
L: Yes. I guess that's what it was, and I remember them moving around, and that's how you figure out how long they are.
J: O.K. Can you think of any reason that the understanding of size, scale, and measurement would benefit you in your future?
L: Yes, of course. [It's like Miss America being asked questions on the spot.] Well, you just need to know where you sit in this world—how big you are, how small you are. I think that's important to know—just to know. I don't know any specific reasons besides that. I mean, you know, you're not as small as some things and not as big as other things. But I don't know how. I don't know.
J: It's O.K. You did fine. Thank you very much.
APPENDIX E: FINAL INTERVIEW QUESTIONS AND RESPONSES

FINAL INTERVIEW WITH ___________________ DATE ___________
CONDUCTED BY JULIANA HINTON McNEESE STATE UNIVERSITY

1. Which of the sessions did you feel was the most beneficial in your understanding of the concepts of size, scale, and microscopy? In what way?

2. Can you think of other applications for the concept map technique that we utilized?

3. When we used the microscope, what was the most memorable activity?

4. Was there a particular procedure which you enjoyed performing with the microscope more than the others? Why?

5. Did the coconstruction of the concept map help or hinder the process? In what way(s)?

6. Did you feel that the choice of activities was conducive to your learning the concept of scale? Which one was the most helpful?
7. What impact will this activity have on the way that you view microscopy?

8. Can you think of another method using microscopy that would enhance your understanding of scale?

This concludes our session. I certainly do appreciate your cooperation with each segment of the research.
FINAL INTERVIEW WITH BILL
BIOLOGY STUDENT
CONDUCTED BY JULIANA HINTON
(TAPE TRANSCRIPTION)

JULIANA: Bill, this is our last interview, and I'm going to ask you some
questions just like I did on the initial one, and just answer the best that
you can. Which of the sessions did you feel were most beneficial in your
understanding of the concept of size, scale, and microscopy?

BILL: Hm-m. I'd have to go with the uh-h, how we had to connect the
microscope, magnification, field of view, and how we had to connect
them all together and put little words in that would connect those, those
ones that we had to connect together.

J: Concept map?

B: The concept maps—

J: Really? O.K. In what way did you think they were useful?

B: They, uh— it started to put everything together, you know. If I'm in a
situation, I'll try, you know, I'll try to figure out the steps it takes to get out
of it, and I'm usually using a concept map because, like say, for like, for
basketball, for instance, because, you know, I'm really surrounded by
basketball, and its like, you got a coach, players, the game, team, and,
you know, all that stuff, and you got to connect all those together. That's
how I pretty much—how I became more knowledgeable of the game—by
using the concept map.

J: O.K. Can you think of other applications for the concept map technique
that we used other than that? Actually, that was a good other way to use
it, than the way we applied it, so that's really the answer to that question.

Well, when we used the microscope, what was the most memorable
activity? When we did the Elodea, which part of that was the most
beneficial? Or most memorable?

B: Watching the little—uh, what was that other—

J: Chloroplast?

B: Yeah, watching those move around—

J: In the cytoplasm.
B: Exactly.

J: O.K. Was there a particular procedure which you enjoyed performing with the microscope more than the others?

B: No, just--

J: Other than the Elodea? We constructed the cells that did the magnification. Do you know what--?

B: Just--

J: You enjoyed the actual visualization of the process of cyclosis the most?

B: Yeah, pretty much.

J: O.K. Did the construction of the concept map help or hinder the process of data collecting?

B: I think it helped. You know, it made me look at scale, weight, and size differently. You know, it helped me to see what the differences are and the similarities. I think it helped.

J: O.K. Did you feel the choice of activities was conducive to your learning the concept of scale?

B: Question again--

J: Did you feel the choice of activities was helpful to your learning the concept of scale?--the different activities that we did during the process?

B: Yes.

J: Which one do you think was the most helpful to help you understand scale?

B: When, uh-h, we had to write as much as we could about our background on scale, size, and measurement. I think that helped me.

J: Your autobiography?

B: Yeah.

J: What impact will this activity have on the way you view microscopy?
B: Good question. Oh. I really can't answer that. I don't know. I can say that it--; Let me hear the question again.

J: O.K. What impact will this activity have on the way you view microscopy?

B: Good question.

J: Did it make any difference to you what we did, you know, during the exercise on the microscope? Does it change, in any way, the way you see with the microscope?

B: Not really.

J: Can you think of another method using microscopy that would enhance your understanding of scale—some other method using the microscope that would have helped you in another way using the microscope?

B: I would say more hands-on use, you know, that would help more.

J: Well, this concludes our session. I certainly do appreciate your cooperation with each segment of the research.

B: You're welcome.
FINAL INTERVIEW WITH FRANK
BIOLOGY STUDENT
CONDUCTED BY JULIANA HINTON
(TAPE TRANSCRIPTION)

JULIANA: O.K. Frank this is our last interview of the project, and I'm going to ask you some questions and just respond naturally.

FRANK: O.K.

J: Which sessions did you feel was the most beneficial in your understanding of the concepts of size scale and microscopy?

F: I would have to say working with the microscopes and the Elodea. At first, I had to actually go home and think about it, and its like--. What actually happened, I knew the field of view. It didn't shrink because it always showed whatever the amount was, but I had to think about that, in my head, in that, even though, you know, it looks like it's gotten larger, my estimate, in the beginning, was still the same. I'm just um-m, kinda zoomed in on it.

J: O.K., thank you. Can you think of other applications for the concept map applications that we used?

F: Um-m, besides science, or just--

J: Yes.

F: Um-m, you could use it in almost anything that you like trying to narrow something down and see how something close from one ordered pair--like kinda branches off and how it works together

J: Very good. When we used the microscope, what was the most memorable activity? Did you find it to be the Elodea as you stated previously or--?

F: Um-m. Yeah, basically just that—that was what made the most like impression and like what I got out of it that made me think about it.

J: O.K. Was there a particular procedure that you enjoyed performing with the microscope more than the others—except for that one?

F: Not really.
J: O.K. Did the coconstruction of a concept map help or hinder the process that we've been conducting?

F: Well, at first I didn't really like understand it all. I just kind like well--I think this goes here and this goes there. After using the microscope and making me think about it--about how the size of the object didn't change and then going back and doing another concept map. I was like able to say, "Oh, now I know why this goes here, and I can use what I had on the microscope." I was able to form a better concept of, you know, and be able to put things in order and how they related and apply what I had learned to it.

J: O.K. Did you feel that the choice of activities was conducive to your learning the concept of scale?

F: Uh-h, yes.

J: Which one was the most helpful?

F: Uh-h, probably again the Elodea thing.

J: O.K.

F: Using it under the microscope.

J: O.K. What impact will this activity have on the way that you view microscopy?

F: Um-m. Well, since I'm not a science major, it didn't have that much of an impact, but it did teach me an important lesson in that not everything that you see is actually what you think it may be. It may be something totally else—and just don't assume. Try to sit down and figure it out scientifically, you know.

J: Can you think of another method using microscopy that would enhance your understanding of scale?

F: Like another experiment?

J: Yes.

F: Hm-m. Not just off the top of my head, but I'm sure there are plenty of things that you could do to analyze size and compare and contrast two things.
J: O.K. Well, this concludes our session. I certainly do appreciate your cooperation with each segment of the research. Thank you very much.
JULIANA: Which of the sessions did you feel was the most beneficial in your understanding of the concepts of size, scale, and microscopy?

LAUREN: The video.

J: In what way?

L: I was actually doing it. It was up to me to figure out measurement and everything.

J: Can you think of other applications for the concept map technique that we utilized?

L: What do you mean?

J: Some other way that one might use that hierarchical method of arranging concepts.

L: As far as measurement is concerned?

J: No, no, just the concept of the mapping process—some other procedure.

L: You can use it for anything— I mean as far as science is concerned.

J: Not necessarily. Could you use it for other things—other than science?

L: You can use it to analyze just about anything.

J: O.K. When we used the microscope, what was the most memorable activity?

L: Chloroplasts moving around.

J: O.K., because of the cytoplasmic movement. Was there a particular procedure you enjoyed performing with the microscope more than the others? The one with the Elodea was that the one you liked the most?

L: We didn’t do any other ones, did we?
J: The one with measurement, size—when we estimated the size. When we drew--

L: That was funny because I drew it really big and really small and--

J: O.K. Did the coconstruction of the concept map help or hinder the process of understanding scale?

L: It just confused me, so I guess it hindered. But I don't think like that. But I don't think in--I mean--. You saw my concept map. I just don't think in hierarchical terms. I mean—to relate things in many ways.

J: O.K. Do you feel that the choice of activities was conducive to learning the concept of scale? Did you understand scale better after the activities?

L: Yeah, yeah.

J: Which of the procedures helped you most with this?

L: I think the video was most helpful because I had--. It was actually hands-on, and I like it better when I'm actually doing something rather than being told about it.

J: A visual exercise. What impact do you think this activity will have on the way you view microscopy?

L: Um-m. I mean now I realize that magnification is important to size.

J: O.K. Can you think of another method using microscopy that would enhance your understanding of scale?

L: Not really.

J: O.K., this concludes our session. I certainly do appreciate your cooperation with each segment of the research.
FINAL INTERVIEW WITH LOUISE
BIOLOGY STUDENT
CONDUCTED BY JULIANA HINTON
(TAPE TRANSCRIPTION)

JULIANA: Which of the sessions did you feel was the most helpful in your understanding of size, scale, and microscopy?

LOUISE: The one where we had to write about experiences when we were little. That kinda made me realize how much I judged things when I was young, and then as I was growing up—the size of things. And then when we did the one on the computer where you had the T.V. screen, and you asked us the size of everything, and I realized how small things were. I don't usually put to scale the little things.

J: Can you think of other applications for the concept map technique that we utilized?

L: Like for teaching or something?

J: Perhaps.

L: What are they usually used for? Well, I think, education-wise, they are important because they group things into—(Gosh, this is hard.) Well, they put everything on a scale for like people who are learning to realize what's the main part of something—what are the compartments of it. I think it's important for learning.

J: There are applications that you're not aware of—people giving talks, people organizing massive amounts of information.

L: Yeah, I guess I've used something like that whenever I've given a presentation.

J: When we used the microscope, what was the most memorable activity?

L: The one we did with the leaf.

J: The Elodea?

L: Yeah. We saw them all moving around and measuring. I haven't looked in a microscope in a few years.

J: Was there a particular procedure which you enjoyed performing with the microscope more than the others?
L: No, they were all pretty interesting. I learned a lot from them.

J: Did the coconstruction of the concept map help or hinder the process?

L: The concept map got me pretty confused. But I guess it helped because I tried to place all those things in a diagram scale--type thing. I learned a lot trying to group all those together. It was not the easiest thing I've ever done.

J: Did you feel that the choice of activities was conducive to your learning the concept of scale?

L: Oh, yeah! Definitely.

J: Which one was the most helpful?

L: Probably the one I did with the T.V. whenever you put it in different aspects and try to estimate the size of them and everything as opposed to a ruler right up next to it.

J: What impact will this activity have on the way that you view microscopy?

L: I definitely won't forget it--the next time I look into a microscope! I'm a lot more aware of what the size of things are now because I never really thought about it. I just took it in and that's it. Now I think I'm gonna take it in and process it a little more instead of spitting it out.

J: Can you think of another method using microscopy that would enhance your understanding of scale?

L: No, I think we did about everything!

J: This concludes our session. I certainly do appreciate your cooperation with each segment of the research.

L: Well, thank you!
APPENDIX F: MICROGRAPHS

OPEN STOMATE


LEAF STRUCTURE

PARENCHYMA CELL

(Mader, Biology, 6/E, 1997, McGraw-Hill)

STATOLITHS

(Mader, Biology, 6/E, 1997, McGraw-Hill)
OPEN STOMATE

(Mader, Biology, 6/E, 1997, McGraw-Hill)

LEAF STRUCTURE

(Mader, Biology, 6/E, 1997, McGraw-Hill)

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PARENCHYMA CELL

STATOLITHS

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Well as I remember in preschool, all the people who told me what to do were very big to me. Size was something that has always caught my attention. That was around the first time I had any dealings with size. I used to hear people say “Size isn’t everything,” and stuff like “The bigger they are the harder they fall” or “She’s as small as an ant.” These sayings are just a few that come to mind that helped me begin to have a concept of size and scale.

It all started in kindergarten. I can distinctly remember the kids and me running around and playing with everything you could get your hands on. Well, as you would know it, we split up into groups. It was the boys against the girls. We challenged the girls that we could build a better castle than they could. Our tools were a bunch of old building blocks. We eventually got the beautiful castle all built up. Sure ours was larger and looked better but we soon found out that appearance is not everything. Well, to make a long story short. The boys ended up losing. Our nice and wonderful castle had collapsed. The reason was due to our inaccurate measurement to fit the board that we placed it on and our oversizing it. Thus, concluded my first endeavor with size and measurement.

In middle school I had to walk to school every morning. I would be (...) because my brother would say it’s just two clicks away. He was in the Army, so he was using an army term which made it seem shorter than what it really was, so I had to continue to walk every day. By this time I started to notice that size meant something because people looked at me differently once I became 6’0.
At the amusement park my size became a factor that determined what rides I could go on.

Just thought I'd add this. Women would sometimes look at a man's shoe size and determine if they were going to sleep with him or not. Coaches from NBA basketball teams would notice a person's height before they notice his criminal record or bad teeth. NFL coaches would pick players with thick thighs that they wanted them to play on their [sic] team.

In junior high school myself and a group of my friends would go camping and see who could live off of the land the best. There was one camping trip that I was the clear and dominant survivor. Our task for that weekend was to build a mini-camp out of the raw resource of the land on which we were staying. Well I took a quick look around to scale the land for certain resources that popped into my head. I saw some palmettos (for the roof and walls), some small and medium branches (for my structure), and some skinny and medium width green vines (for some type of rap around support). My plan was then into action. I quickly gathered all of my resources and began building. I can distinctly remember the hard time I had with the tie vines so I had to switch to something else. I began to restructure my camp. I adjusted by using branches with some type of a forking shape at the end. My second plan worked. I remember myself precisely placing and measuring everything to the best of my ability. The careful work had paid off. Later that night my friends and I decided that my camp was the best and we all shared it that night.
This recollection deals with scale more than any. It all began with my friends and my hatred of our science teacher. She was very cruel and unjust. She had this fish in an aquarium in our classroom. She was very proud of it. Well, we would observe the fish nearly everyday; until one day she pushed us too far. We formed a plan to borrow the fish from her. So we did. My friend brought what he thought would be a sizeable container to heist the fish and store it in. Well, getting to the chase, we almost got caught with this fish because the container was too large. When the fish was in the water, he looked a lot larger than he actually was. The fish being missing is now noticed by the unjust one (the teacher). Where our plan almost crashed was when we couldn’t go directly home after school. So, we had to store the container in my football locker. The deal was, was that if we would have observed the fish a lot closer; it would have been easier to take. We could have simply used a smaller container. Thus, making it easier to hide until we could get off campus. Needless to say, the heist was a success. For the next few weeks the teacher pounded her classes with threats for the convicted crooks who stole the fish. Well, like I said earlier, we didn’t steal it, we borrowed it. So we continued to go through the weeks of her anger. Finally, before the school year ended, we returned the fish; and low and behold, the sweetest revenge of all came. The fish that we had borrowed, had eaten her new pride of fish without her knowing that it was even there. When she noticed this she was very, very angry and shocked that her fish had mysteriously returned weeks later.
I would drive to New Orleans from Lake Charles, and I would not look at it from a miles standpoint I would look at it from a time standpoint. I figured out it would take me 3 hours or 18 miles to drive from New Orleans to Lake Charles. From my house on 5th Avenue it takes 5 to 7 minutes to get to school. That's about 5 to 6 miles. Size has always been a big part of my life. The reason is because I love to play basketball. Your height and weight can make you a lottery pick or a second round draft pick. The taller you are the better chance you have. I always knew size would make sense to me, but I never thought of it every day; more or less, I would take the concept of it for granted.
Frank's Autobiography

Starting with preschool there is very little that I can remember about size and scale except that I remember everyone older was bigger and stronger than I was. I remember the difference in size between my parents shoes and my own, and I can also remember how my father would let me drive the car. The exception was that I had to sit on his lap because I couldn’t reach the pedals yet. However, I was aware that my body was changing. For example, the tricycle that I used to ride was replaced with a bicycle, and I no longer felt that I was the smallest because now I had smaller brothers and a smaller sister.

As I started elementary school (1st - 5th) grades, I remember one project in particular that relates to measurement. In the 2nd grade, my teacher used a "walking ruler" to measure distance throughout the school. Every click heard from the rolling ruler meant one foot, and we measured the distances from our classroom to the principal’s office, to the restrooms, or the cafeteria. Projects from art class also come to mind. I remember drawing my hands or having someone drawing an outline of my body so that we could make a 3-D replica of our own bodies.

Family vacation helped me distinguish between scale and distance. I can remember being given the map and having to figure out how far we were from our destination and how long it would take for us to get there. I think that was my dad’s way of not having to answer that age old question, “How long until we get there?”, since I could already add and divide. Working puzzles of the U.S. also helped me to gain a feel for distance and relevant position.
The walking ruler in 2nd grade and figuring out distance and time using a road map helped me understand the relevance between my current position and the time and energy it would take me to move to another location. This concept is essential to planning/budgeting your time. A person needs to be able to figure out when he/she needs to leave in order to reach a certain destination at a certain time.

At my grandmother's house, my dad would mark my height on the door post, and I could weigh myself on her bathroom scale. I can still remember the 1st time that I weighed over 100 lbs. I was probably in the 5th grade.

The first time that I had to apply the metric system was the summer between 6th and 7th grade. We took a family vacation to Canada. Trying to figure out distance wasn't a problem because our car had kilometer marks underneath the mile marks. I knew that if we were traveling at the posted speed limit of 100 kmph, we were traveling at 60 mph.

The problem that we ran into was when we put gas in our car. We were trying to figure out how many liters made a gallon and then trying to figure out how much it cost us to fill up our van in U.S. dollars. I remember that my dad put 40L in our van.

My metric experience in Canada taught me that large numbers don't always have to represent large distances. Although distance is constant [sic], the measurement that is used to measure the distance can either be a high or low number.
Another memory about distance that I have from middle school was traveling to Baton Rouge with my father across the Atchafalaya Bridge. My father kept his speed constant at the posted speed limit of 60 mph. He gave me his stopwatch and had me start it as soon as we reached one of the emergency call boxes that are posted along the freeway. I learned that the call boxes were spaced 30 sec. apart at 60 mph. Using my father's odometer, I learned that if you are traveling at 60 mph you are roughly traveling at one mile every minute. Thus the call boxes were placed 1/2 a mile apart from each other.

As I advanced into middle school, my use of measurements began to become more scientific. In 7th grade I remember using a microscope for the 1st time and being able to see cells. We used time and measurement and scale in high school. In the 9th grade my science teacher gave us 10 oranges and by following an outline and using a yard stick, we were able to see the distance of the planets in our solar system as they were from our sun. Another memory—or should I say nightmare—of size and distance was the first time that I had to parallel park. My experience with parallel parking in driver's ed taught me that, although distance never changes, it can be relative to one's perception. Looking out of my rear view mirror and side mirrors, I always believed that I was closer to the other cars or the curve than I actually was. In Band we used measurements to set drill on the field. We all had to take an 8 by 5 step, meaning we had to take eight steps for every five yard lines. Finally, my senior year, we measured the distance and time that it took us to walk or run a specific

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distance while performing certain tasks. We calculated the mean and tried to explain the differences in individuals i.e., height, weight.
Lauren's Autobiography

Any memory about measurement was impressionable because I compared my own size to the size of things around me. It was almost as if size was directly related to my place in society. As a child, the smaller you are, the lesser the importance is that others place on what you do or say. Adults hover around having adult conversations and doing adult things, and children just get lost in a forest of murmurs.

Size eliminates children from many adult activities. Some businesses such as restaurants or theme parks that cater to children do so by having items like chairs or doors sized to accommodate children. This is important because places sized for children exclude adults and create a society that is reversed from reality, the smaller the better.

Everything is big to a baby so from the beginning, a child begins to learn about size, scale, and measurement from the first things it sees and holds, i.e.: bottles, rattles, fingers and toes, people's features...room size, etc. In the game of hide-n-seek, size plays a big part in finding the perfect hiding place.

Strange as it is, I have a very vivid memory of looking through baby bed bars...knowing my head wouldn't fit through them. I also remember figuring out how to climb out of that bed. One foot over first, knowing if I held on to the solid end of the bed, I could let myself down until that foot reached the other foot over and stand on the mattress between another two bars. Holding onto the top of the bars, I'd slowly and carefully let myself down until I could reach the floor. That all took some figuring.
One of my earliest memories is of my father standing over me, looking down. I was just a toddler, and my father seemed a giant. But as I grew older and taller, my perception changed as my world changed. What exactly was one's size? How do I measure it? What does it all mean?

My parents knew the remedy. So, off I went, my hand in my mother's, to face a new challenge: kindergarten—a land of learning. Here my tiny world met its judge: the ruler. How tall am I? How long are my fingers? How big are my feet? It was all measured and tallied up in whole numbers and parts, and I could now look up at my father and say "Well, you may be 5 feet and 10 inches tall, but you're only 3 feet taller than I am—you're not such a giant after all." A big step for tiny feet, which I could now actually measure and find the size of.

We used to love to dip saltine crackers and cookies in milk. We figured out the best glasses to use. Some were too narrow where you couldn't get your hand and the cookie into. Others were too deep. They'd hold too much milk per cookie. So we had our favorite cookie and milk glasses. And we also got a spoon for the one cookie that got away.

We had a big bulletin board where we'd hang our drawings and paintings. We'd always try to cover the cork without overlapping the drawings. That took some figuring and measuring.

I remember that strange metal shoe sizer the salesmen used every single time in the shoe stores. It measured the length and width of your foot as you stood and put your weight on it. I knew each time I went, the numbers would grow because I was growing.
At dinner my mom used small plates for the young kids, divided Blue Willow plates for middle age kids, and large dinner plates for adults. They were always very full when she served them making them look alike, until they sat beside each other on the table. Then you could see they scaled down from large to small, making each portion do the same. Our waists always measured larger after her meals, so we’d move out belts to the next hole, making a larger size.

When visiting Pontchartrain Beach in New Orleans, I remember having to be measured in height before we could ride the giant roller coaster. It was explained to us that shorter ones could actually slip through the bars. So for years I stood and watched my older sister and cousins ride. There was however a roller coaster for little ones, too. It measured half the size of the giant one and we loved it. We fit in those little seats as they were scaled down to fit us and the ride wasn’t scary at all. The “hills” in the ride measured much lower and the speed was much slower. Looking at the two together, they looked like a mother and baby.

My sister’s blouses would fit me but our shapes were different. She was taller so her blouses were longer on me. She was larger in the bust line than me, but my broad back filled space, so they fit us both just fine. My mother sewed most all our clothes. She’d leave large seams in my older sister’s dresses because she knew I’d be right behind her to hand them down to me. I was heavier (and shorter). When she outgrew her clothes, Mom would let out
the waist for me, scale down the shoulders and shorten the hem. Then it was "my very own" dress.

We were aware of outgrowing our clothes with the change of seasons. We always knew the clothes we put away would be too small when we'd take them out. It was very sad to have to let go of that favorite sweater or sun dress because it was too little. But we always knew someone smaller who could wear them.

Many games required us to know size, scale, and measurement: making roads and road maps for our road maps for our matchbox cars, treasure maps, tunnels, bridges, hopscotch...one hopscotch required us to draw a perfect square with 9 squares inside.

As time went by, I grew and found new tasks. Early one morning, just before my grade school recess, I was presented with a map of the United States. I had been exposed to similar maps before, of course, learning to put a puzzle of the 50 states together, but until now, it all meant nothing. Now I had new questions to heap on all those I had asked in childhood. How could the state that I lived in be only an inch tall? I was taller that an inch, but I, and all my classmates, still fit. The answer was scale. On paper, 1 inch could represent 500 miles. What a relief.

Mom gave us material scraps to make doll clothes. We made patterns from paper, measuring the dolls trace their bodies with a pencil, always leaving enough for sewing the seams. We'd wrap material around the baby dolls' backs of their heads, cut it in the shape of a bonnet, then lay it down and trace that on
paper. We'd measure the outside rims of the bonnets, and cut ruffled lace that was the same measurement. A few stitches to the bonnet base, and voila, a baby bonnet. Cutting the right length of the ties for the bonnets was always tricky because we'd try to tie them in a bow before cutting them from the roll. Momma taught us to tie a little knot at the end of each ribbon, just for appeal, so we always had to allow for those knots.

As a small child, to reach the bathroom sink to brush teeth, we used a foot stool with fold-down steps. The larger kids didn't have to fold the step down. The even larger ones didn't have to use the bench at all. We all knew what size we'd have to be before we wouldn't need the foot stool at all.

My sister and I displayed our dolls on the top of our chest of drawers in the same fashion as we had stacked canned goods on the pantry shelf, the large ones in the back scaled down to tiny miniature ones in front.

Bikes are a constant in many kids' lives. We learned quickly the size of our wheels, 22" or 26" bikes and how they rode...the larger wheel turning slower so the pedaling was less. Also our knees would hit us in the face on the smaller ones, but we'd have to stand on the lower step to climb onto the large bikes.

Sports played a huge part in teaching me size. In softball, for instance, the size (length, thickness, and weight) of the bat had to be considered in relation to the batter's size (height, weight, and size of hand grip); how many steps it took each player to get to first base. Gymnastics, track, football, you name it, and you can learn lessons in size, measurement, and scale.
Balancing groceries in our bicycle baskets was always a challenge. Like a set of scales, we'd try to figure the weight...1 lb. Butter and a loaf of bread and a box of crackers to ½ gallon of milk on the other side...same with our school books. Those side saddle book bags that hung on each side. We had to learn what size and weight of the books would work so we'd be balanced enough to ride our bikes home.

I was once told by a friend that every child should ride a tricycle for as long as possible because it helps teach the skills of driving a car...unlike a 2-wheel bike. I'd never thought about that until she made me. You can back up on a tricycle and even parallel park. It also takes curves and turns more like a car because of the two wheels in back.

Middle school brought the introduction of metric units. They were easier to use, and I kept wondering why America didn't use them.

In high school, we sewed a long narrow scarf made of 6 hues of the same color. We cut strips of material on the bias, using many strips of each hue. We had to figure how much material to buy to make a certain length. It was very confusing.

In high school gym dressing rooms, size, measurement, and scale played a big part. Anatomy was the big interest...the bigger the better for the boy’s gym; the opposite for the girls, with the exception of the mammary glands, of course. Females are tortured with the “thin is in” rage early on. Therefore, they know all about size, scale, and measurement, i.e. the sizes that are related to the word “FAT”, the weighing scales, of course, that are constant
reminders of the battle of the bulge. And how could they forget the perfect female body measurements of 26-24-36. In spite of the fact that measurements were banned in the Miss America Pageant several years ago, there is not a feminine female who hasn’t abused the tape measure by secretly MAKING her body measure those numbers by either tugging and pulling or padding and lifting.

Men, on the other hand, are known to pad the heels inside their shoes with lifters, to add height. And I won’t even go where the rumors of socks being worn in other places besides the feet, to add bulk and inches, again, hitting on size, measurement, and scale.

I remember once planning a bedroom window escape in the middle of the night...the reason? To see if I could do it successfully! I lay in bed (about 11, I’d guess) and planned it, with a lot of thoughts about measurement. Our windows were way off the ground so I knew I’d have to use a chair to climb back in, not to mention climbing out. A rope could lower it but I’d have to remember to climb back in WITH the rope, probably in my mouth because I’d need my hands climbing back in. I was afraid the chair would bang up against the wall, dangling from the rope, though, waking up my parents, so the rope was out. I figured I’d have to pick a chair that had a high back, enough that I could reach it from the window sill to lift back into the room. The perfect chair sat in the corner of my bedroom. With perfect planning of size, scale, and measurement, my silent Great Escape and return was successful.
Chemistry and physics caused me more trouble than I expected. With the introduction of the mole (6.02 x 10^{23} particles) and the detailed examination of distance and mass, measurement became a real part of what happens every moment of life. As I began to drive, I attempted to figure how much distance was needed to stop my car when I was going over 35 miles an hour.

Now, biology doesn't use near as much measurement as physics did, but when comparing the size of a cell to the size of the organism in which it resides, measurement becomes important enough to be recognized.
Louise’s Autobiography

Growing up by a lake gave me the opportunity to compare myself to something much bigger than me at an early age. I remember going on a vacation with my family to Florida when I was at most 5 and although I don’t remember much, I do remember looking out from our condo and seeing only water, no land. I couldn’t imagine that there was any body of water so big that you couldn’t see the land on the other side. That experience made my perception of Lake Charles (the lake) totally change. I realized that the city I thought I saw was just industries no more than 2 miles away.

In preschool I remember a favorite rocking horse of mine that I played on constantly. I remember thinking it was huge, almost as big as a real horse. Years later, however, after it had been stored in the attic, I took it down and realized it was tiny, barely 2 feet tall and no more than 3 feet long. In my head I can still picture it the way I used to.

In preschool, I knew that my parents were bigger than me, but most of my world consisted of kid size things. The chairs in the classroom were just small enough for 6 year olds, and the books they used to teach us with were large print, so that we could see the letters. Size only mattered when Mom and I went to the grocery store, and I couldn’t reach the cereal that I wanted. It only mattered when I tried to pair a Barbie doll with a G. I. Joe.
I also remember wearing Mom's heels around the house playing ladies. She had tiny feet and mine were not so small. First they were too big, then they were not so very big. She wore a size 5 so I knew when my foot reached that size, they would fit, and they did, perfectly...I, was about 11 years old, far too young to wear black patent heels, toeless, with a black strap across the back. They had a black patent bow on top, and I loved those shoes.

Of course, I remember best drawing pencil marks on the wall, measuring heights as we grew. I remember measuring my height from my dad's belt buckle, then the buttons on his shirt. How strange it is to actually remember that I reached his belt buckle, and then the day I reached the first button above the belt buckle!

In first grade, the teacher was tall and thin. Her desk was this over-sized brown box, perfect for hiding underneath. The older kids were giants to us. Throughout elementary school, we learned that 12 inches made one foot, but not much more.

Walking to school, we knew the distance by the number of steps. We'd measure the blocks by the number of lines on the sidewalk, and we knew we were getting closer to school as we passed the telephone poles and they got larger and larger the closer we would get to school.

In elementary school I remember one day in 3rd grade when we were talking about measurements with our rulers. We had become familiar with the length of an inch and a foot and soon, however, I remember one classmate having to go up to the board,(something much bigger than our piece of paper
usually in front of us), and draw what he thought as a 4 inch line. After he drew it, I remember thinking to myself that he didn’t draw it long enough, however, when the teacher took a ruler and measured the line, it was over 1 foot long. I remember being so surprised and thinking to myself that I really hadn’t grasped the concept of measurement yet. I could do it when it was on my usual size sheet of paper that I had learned on, but when it came to bigger or smaller things, my concept was distorted.

I used to play basketball from 5th to 7th grade and I remember my perception of the basketball court and the gym, and how big it all seemed to me. Now when I see the same courts, they seem so small, and that doesn’t seem all that long ago. I wasn’t much shorter in 7th grade than I am now, just about 4-5 inches. It doesn’t seem like that perception was compared so much to how big I was, rather it seems that the more I learned and the more, bigger places I went as I got older changed it.

Also, I had a pool growing up, and I remember thinking of it to be as large as an Olympic size pool, even after going to a local club where there was an Olympic size pool. I swam in both pools, and I still thought mine was just as big. Then, I remember doing an experiment to measure the pools by testing how many times I could swim the width and length of my pool with one breath. I soon realized after getting to the big pool, that my assumptions were very wrong. It’s so interesting that as a young child, almost all things much bigger than me all seemed relatively the same size. My concept of measurement did not develop until I started elementary school.
In middle school, in the 8th grade, I switched schools. I started going to a school much further out than my original one. The friends that I made all lived in the new part of town which was 10 or so minutes from the old part. It seemed like they lived so far away from me. I remember thinking how far the new part seemed when I was even younger, than in 8th grade, then now I have 3 totally different concepts. After getting my license and a car, everything changed of course, and now after living in Dallas for two years, I think it has changed a 4th time. Everything seems so much closer, so much smaller. I know, however, that everything is not as close and small that it appears, it’s just that in today’s world we have so many fast ways to get around and no matter what, we still can’t move fast enough! I believe that this gives us the illusion of everything around us being small when really it’s all a lot bigger than we think.

In 8th grade science, we did several different experiments with microscopes. I remember one day we looked at everyday things under the microscope, like hair, fingernails, and any other commonly seen things. I remember being pretty “grossed out”, but mostly amazed at how complex something I always thought of as so small actually was.

In high school, I remember studying the periodic table in chemistry and I remember my teacher trying to explain to us how small atoms are, yet how complex they are. I remember thinking that maybe they aren’t that small, it’s just that we’re a lot bigger than them. That doesn’t necessarily mean that they’re that small, only in comparison to what we are familiar with. That same year in my English class we were talking about our theories on life and a friend...
of mine brought up the subject of atoms and how they resemble our solar system. Her theory was that our solar system is one of millions and billions of atoms, maybe floating around in someone’s body somewhere, and all of the atoms in our known world are really solar systems with life somewhere in them. The cycle goes on and on. Although this is quite unlikely, it really made me think about size and how little I really know about its whole concept.
APPENDIX H: MICROSCOPY EXPERIMENTS

EXPERIMENT ON MICROSCOPY

Learning Objectives

Students should be able to
1. Name and give the function of basic parts of the microscope.
2. Understand the concept of depth of field, parfocal, and resolving power.
3. Calculate the diameter of field and total magnification for both the high and low power lens systems.
4. Focus the compound light microscope by using the proper sequence of steps.
5. Name the linear units of measurement in the metric system and be able to convert between the units.
6. Prepare the wet mount of the Elodea anacharis plant.
7. State the parts of the Elodea cell—sketch and label them on low and high power.

The instructional portion of this exercise will be conducted with the use of overheads. Sketches by the students will be saved for critiquing.
1. Field of View = 1.5 mm

2. Estimate the cell size on low power!
   (1500 mm = 15 mm)
   150 / 4 mm

3. The same

---

I'm using 10 cells as my field of view.
10 x 10 = 100x

40 x 10 = 400x

Field of View = 1.5 mm 1.506 mm

Estimate cell size on low power = 100 um

15 cells

Estimate cell size on high power = 250 um

6 cells
1. 1.5 mm = field of view
2. Estimate cell size on low power
   1500 micrometers = 1.5 mm
   \[ \frac{15 \text{ cells across}}{100 \text{ micrometers}} = 10 \text{ microns} \]

\[ \text{cell} = \frac{1}{10} \text{ mm} \]

3. Estimate the cell size on high power
   \[ \text{same cell} \]

\[ \text{1 cell} = .1 \text{ mm} \]
1. Field of View = 1.5 mm
2. Estimate cell size on low power:
   (1500 μm = 1.5 mm)
   150 μm = .15 mm
3. Estimate cell size on high power:
   150 μm = .15 mm
APPENDIX I: LETTER OF SUPPORT

December 7, 1998

Dr. George Mead
Dean, College of Science
McNeese State University
Lake Charles, Louisiana 70609

Dear Dr. Mead

At the beginning of the spring semester, I will be collecting data for my dissertation topic, "A Narrative Explanation of How We Learn Measurement and Scale and How This Knowledge Can Be Enhanced If Studied in Conjunction With Microscopy". Volunteers of students in my classes will be the participants in the study. McNeese has been chosen as the site for collecting data because of convenience.

The nature of the topic requires that I conduct interviews, perform some laboratory activities, and present concept mapping exercises to the participants. Prior to the research I will present a thorough description of my intentions to the students explaining the procedure and purpose for collecting the data. All participants will fully understand that the information will be made available to them to review the findings before the results are submitted. Human Subjects Guidelines for McNeese as well as those of Louisiana State University will be carefully followed. These forms will be approved prior to data collection.

A copy of the Human Subject Forms will be sent to you as soon as approval is completed. I want to thank you for supporting me in the past and I would appreciate your support as I continue with this endeavor.

Sincerely

[Signature]

Juliana Hinton
Doctoral Candidate
Department of Curriculum and Instruction
Louisiana State University
TO: Julianne Hinton  
McNeese State University  
P.O. Box 92000  
Lake Charles, LA 70609  

Date: April 05, 1999  
Invoice Number: 54163  

Fees: $0.00  

The McGraw-Hill Companies material requested:  
Title: BIOLOGY, 6E(1997)  
Author(s): Master, S  
Specific material: Figures 31.5(a) on page 534, 31.18 on page 548, and 32.6 on page 558, only.  

For inclusion in:  
Title: A NARRATIVE EXPLANATION...  
Author(s): Hinton, J.  
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Ms. Juliana Hinton
McNeese State University
Biol/EnSc Department
P.O. Box 92000
Lake Charles, Louisiana 70609-2000

Dear Ms. Hinton:

This is in reply to your fax of yesterday, in which you requested permission to include in your doctoral dissertation a figure which appears in Anton Lawson’s chapter in Gabel, ed.: HANDBOOK OF RESEARCH ON SCIENCE TEACHING AND LEARNING.

Please note that Fig. 4.5, "The epigenetic landscape of the developing individual" is cited as "From Waddington, 1966." The actual book source as indicated in Lawson’s References section is:


This was a title in the Current Concepts in Biology Series, published by Macmillan’s former College Division. Permissions for these books are handled by Prentice Hall at One Lake Street, Upper Saddle River, NJ 07458 (Permissions Dept. fax: 201-236-3290).

I am forwarding a copy of this letter, with your request and the Waddington contract on microfiche, to Michelle Johnson at Prentice Hall College Permissions. If you should need to follow up with her by telephone, the number is 201-236-3281.

Best wishes.

Sincerely,

Lydia Zelaya

cc (with Enc.): Michelle Johnson

April 3, 1997
APPENDIX K: INSTITUTIONAL REVIEW BOARD PERMISSION FORMS

TO: Ms. Juliana Hinton

DATE: March 5, 1999

SUBJECT: Research

Dear Ms. Hinton:

We are pleased to inform you that your research project entitled "A Narrative Explanation of How We Learn Measurement and scale and how this knowledge can be enhanced if studied in conjunction with microscopy" has been approved by the Human Subjects Institutional Review Board of McNeese State University. Your proposal appears to be in compliance with the federal regulations concerning the use of human subjects.

Please retain this letter of approval and the proposal you submitted. If you have any questions, please contact me at 475-5285.

Sincerely,

Peggy L. Wolfe, Ph.D., R.N.
HSIRB Chairperson

PLW/rrh
APPLICATION TO CONDUCT INVESTIGATIONS
IN WHICH HUMAN SUBJECTS MAY BE AT RISK
MCNEESE STATE UNIVERSITY

IF ADDITIONAL SPACE IS REQUIRED TO RESPOND FULLY PLEASE CONTINUE ON THE BACK OR ON CONTINUATION PAGE

1. Title of Proposal (copy of proposal must be attached) A NARRATIVE EXPLANATION OF HOW WE LEARN MEASUREMENT AND SCALE AND HOW THIS KNOWLEDGE CAN BE ENHANCED IF STUDIED IN CONJUNCTION WITH MICROSCOPY

2. Names of investigator(s)

3. No hazard exists (X). A possible physical, mental, psychological, sociological or other hazard exists ( ). How will risks be controlled?

4. a) The subjects in this project will be:
   1. students from selected (X) or randomly selected ( ) University classes.
   2. students from selected ( ) or randomly selected ( ) public schools.
   3. randomly selected non-student adults ( )
   4. other selected subjects (explain). ________

   b) Approximate age of subjects 0-20

   c) Method of recruiting Requested volunteers

   d) Approximate number of subjects 1

5. Informed consent is required by University policy and DHMR regulation. Attach a copy of the written consent form.

6. Confidentiality of information from or about subject must be safeguarded. How will you maintain confidentiality? Pseudonyms will be used.

7. Potential advantages to subject? Yes (x) No ( )
   If yes, explain: Students will have an opportunity to participate in a scientific research project.
8. a) Is the experiment a part of a course in which the subject is enrolled? NO
b) Is participation in the experiment a requirement for the course? NO
c) If a or b are answered yes, please explain the nature of the requirement.

9. Please attach any other information you can provide to assist the Institutional Review Board for the protection of human subjects.

*Student research requires the signatures of both the study director and the student.
**Department Chair approval and signature required before IRB review.
ASSURANCES

As the principal investigator for the proposed research study, I assure that the following conditions will be met:

1. The human subjects are volunteers.
2. Subjects know that they have the freedom to withdraw at any time.
3. The data collected will not be used for any purpose not approved by the subjects.
4. The subjects are guaranteed confidentiality.
5. The subjects will be informed beforehand as to the nature of their activity.
6. The nature of the activity will not cause any physical or psychological harm to the subjects.
7. Individual performances will not be disclosed to persons other than those involved in the research and authorized by the subject.
8. If minors are to participate in this research, valid consent will be obtained beforehand from parents or guardians.
9. All questions will be answered to the satisfaction of the subjects.
10. Volunteers will consent by signature if over the age of 6.

Principal Investigator Statement:

I have read and agree to abide by the standards of the Belmont Report and the Louisiana State University policy on the use of human subjects. I will advise the Office of the Dean and the University’s Human Subject Committee in writing of any significant changes in the procedures detailed above.

Signature

Date

Faculty Supervisor Statement (for student research projects):

I have read and agree to abide by the standards of the Belmont Report and the Louisiana State University policy on the use of human subjects. I will supervise the conduct of the proposed project in accordance with federal guidelines for Human Protection. I will advise the Office of the Dean and the University’s Human Subject Committee in writing of any significant changes in the procedures detailed above.

Signature

Date

Reviewer recommendation:

☐ exemption from IRB oversight. (File this signed application in the Dean’s Office.)

☐ expedited review for minimal risk protocol. (Follow IRB regulations and submit 2 copies to the Dean’s Office.)

☐ full review. (Follow IRB regulations and submit 12 copies to the Dean’s Office.)

Name of Authorized Reviewer (Print) / Signature / Date
VITA

Juliana Guillory Hinton was born on September 9, 1943, in Lake Charles, Louisiana. She was the middle child of Julian Guth and Molly Hennigan Guillory. Flanked on either side by two brothers, she recognized the magnificence of the outdoors at an early age. Memories of hunting birds, frying fish, and admiring colorful flowers were deeply imprinted and probably were the roots for her career in biology. She received her bachelor's degree in biology education (1970) and master's of education in biology education (1976) from McNeese State University. Her mini-thesis, directed by Dr. William Iglinsky, was on aphids of Southwest Louisiana.

Throughout Juliana's education in Lake Charles, the public schools of Calcasieu Parish which she attended provided master teachers. She is proud to be a product of this system and even prouder to be part of the tradition. From 1969 to 1971 she taught biology at LaGrange Senior High School, and from 1971 to 1979 she taught biology at Barbe High School. At Barbe she instructed Phase III (Honors) biology and planned and implemented the first advanced biology. In 1976 the Louisiana Academy of Sciences selected her as the Outstanding Science Teacher of the Year.

In 1979 with the challenge of motherhood for the second time (number 1 son, Michael Alan, is an orthopedic surgeon, married with 3 children), Juliana left public education to devote time to her second son, John David. By 1984, with McNeese seeking a freshman lab instructor, employment became attractive once more. For five years she was a visiting lecturer teaching
anatomy and physiology, lectures and labs, and freshman biology, lectures and lab. During this time she accumulated credits toward the +30 and eventually began her pursuit of a doctorate. Currently she is an assistant professor in the Department of Biological and Environmental Sciences at McNeese State University, instructing biology for non-majors and coordinating the freshman labs. Freshman lab coordination led Juliana to apply for a Gaming Revenue Grant, which brought $50,000 worth of new equipment to the department.

Juliana has pursued scholarly activities throughout her career. She has given a presentation for the Louisiana Academy of Sciences, the Southwest Educational Research Association, and the LSTA-LABE Drive-In Conference. She has served as chairman of many committees in the community as well as the university. Presently she chairs the Student Relations Committee and is treasurer of the Faculty Senate. She has attended national conferences, including the National Association of Biology Teachers, the National Science Teachers Association, the National Association of Research in Science Teaching, the 52nd Annual Meeting of Microscopy Society, Chautauqua, and the Sigma Xi Forum. She has also attended LASER, LaSIP/LaCEPT, and other state conferences. In 1968 Juliana began assisting with the Regional Science Fair at McNeese. Serving as Co-Director, board member, and judge, she continues this endeavor. Annually, surrounding libraries and schools request her to present information to young people interested in entering the fair.

Dr. James H. Wandersee, Juliana's major professor in the Department of Curriculum and Guidance at Louisiana State University, provided expert
guidance with her dissertation—a narrative study of selected introductory college biology students' struggles to gain an understanding of scale and measurement. She will receive the degree of Doctor of Philosophy at the Fall Commencement in December 2000.
DOCTORAL EXAMINATION AND DISSERTATION REPORT

Candidate: Juliana G. Hinton

Major Field: Curriculum and Instruction

Title of Dissertation: A Narrative Study of Selected Introductory College Biology Students' Struggles to Gain an Understanding of Scale and Measurement

Approved:

[Signatures]

EXAMINING COMMITTEE:

[Signatures]

Date of Examination:

May 11, 2000