

Conveying the Difference in Relative Sizes between Microscale and Nanoscale Objects
at a Middle-School Level

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Introduction

Nanotechnology has become an increasingly important area in science and technology due to its innovative and useful applications. It has been estimated that by year 2015 the global marketplace for products that use nanotechnology will reach US\$1 trillion and employ two million workers (Arrison, 2006). That will happen about the time when today's elementary students are entering college and middle school students are entering into the work force (Edu.Inc, 2004).

Not surprisingly, the US Government Administration has made the National Nanotechnology Initiative (NNI) a top science and technology priority, and it is now recognized that education in this field should be promoted to enable a new generation of skilled workers well versed in the multidisciplinary perspectives crucial for the rapid progress in nanotechnology (The National Science and Technology Council [NSTC], 2000).

Accordingly, researchers and educators have recently stressed the importance of our children becoming "nano-literate" in order to meet the future needs in this field (NSTC, 2000). It has then become imperative to start educating our middle school students to become aware of nanotechnology, getting them interested in the field, and at

the same time create a deeper understanding of the underlying concepts of nanoscience. These efforts will result in future students interested in pursuing a degree in one area related to nanotechnology, and eventually become capable to fulfill this need.

Nanotechnology is built on the foundation of nanoscience. Nanoscience is the study of phenomena on the scale of approximately one to 100 nanometers; namely nanoscale. Since nanoscale is an abstract concept and humans are not able to perceive it with the naked eye; our identified problem is well described by N. Sabelli et al. (2005) as: “The problem is conceptual and practical; objects and concepts at the nanoscale are hard to visualize, difficult to describe, abstract, and their relationships to the observable world can be counterintuitive (p.3).”

Notions of scale have been identified as one of the four powerful common themes that transcend disciplinary boundaries and levels. (American Association for the Advancement of Science [AAAS] 2006). On the other hand, and as explained by Marsh, Parkes, and Boulter, (2001), there has been very little research on children’s understanding of scale. There is also a tendency of teachers of underestimating the scale aspect of representation of an object and do not spend enough time teaching scaling concepts.

This study is focused on the problems and limitations found at the middle school level related to conveying the difference in relative sizes of objects that cannot be seen with the naked eye. The goal is also to suggest strategies that could serve as a foundation for developing instructional materials that will address the identified need.

The results of this study will become the pedagogical foundation for the project generation nano. Generation nano, focused at middle school level students, is part of the

Network for Computational Nanotechnology (NCN). The goals of this effort are a) to start educating our middle school students to become aware of nanotechnology, b) getting them interested in the field, c) create a deeper understanding of the underlying concepts of nanoscience and nanotechnology, and at the same time d) provide to educators and parents the tools, techniques and resources to attain this goal. The ultimate goal of the project is to convey the big nano ideas (Krajcik n.d., p.29). These big nano ideas include topics such as a) size and scale, b) properties at nanoscale, c) the particulate nature of matter, d) self assembly, e) modeling and tools, and f) nature of science and technology.

The focus of this project is on size and scale. Therefore, the instructional goal is that after interacting with the materials, learners will be able to identify nanoscale objects, as different from microscale objects, and provide examples of nano-sized objects.

Approach

The framework for this project was based on studies undertaken in two domains. One was the formative and summative evaluation reports from several museum exhibits and universities that have produced instructional materials in the form of exhibits, websites, or other types of media. The other one was through journal articles identifying the well documented strategies that have been used to teach some concepts related to molecular theory and how those may apply for conveying the concept of nanoscale. These two sources or domains were selected first because there is little documentation of teaching and learning nanoscience related concepts in formal educational environments therefore the focus on informal settings; and second because it was observed that some of the problems in conceptual understanding to convey the molecular theory are very closely

related to the underlying conceptual understanding of nanoscience,

The informal science education environments reviewed were:

- NanoZone at Lawrence Hall of Science, University of California, Berkeley
- Its a NanoWorld at Ithaca, New Yorks Sciencenter
- NanoSense at <http://www.nanosense.org/index.html>
- Marvelous Molecules: The Secret of Life at New York Hall of Science
- Nanotechnology at Discovery World Museum, Milwaukee WI.
- Strange Matter, a travelling exhibit and at <http://www.strangematterexhibit.com>.
- NanoKids at <http://cohesion.rice.edu/naturalsciences/nanokids/>
- Too Small to See at Ithaca, New Yorks Sciencenter
- Nanotechnology: small science, big deal at the Science Museum, London.

Our purpose for reviewing these materials was to identify through their evaluation reports their learning goals, the instructional strategies that were used, and how effective these strategies resulted in conveying their learning goals. In addition, from the second domain, it was identified that the concept of atom and the particulate nature of matter are science concepts that are a) the basic conceptual framework of nanoscience, b) introduced at a middle school level within a classroom setting, and c) part of the National Science Standards.

Literature review

Problems in understanding scale

The literature review is the synthesis of both domains and is presented in the following sections. Our focus was on identifying a) problems encountered in

understanding the concept of nanoscale, b) critical aspects to be considered for teaching nanoscale related concepts to middle school students, c) identification of the level of attainment of the concept of nanoscale, d) learning strategies proved to be successful while conveying concepts related to molecular theory, and in particular e) analogies and metaphors as the learning strategy for that may be applied for conveying the difference in relative sizes between nanoscale and microscale objects.

From surveys conducted in informal educational settings, it was found that the general public have limited knowledge and consistent misconceptions about atoms, molecules, DNA, cells, and other things the interviewees cannot see (Edu.Inc, n.d.); misconceptions such as the smallest thing that they can think of is something they can actually see (early elementary students) or objects at the microscopic scale (Holladay, 2005). Another common naive conception is the fact that most of the interviewees had no working concept of one billion and did not understand 10^{-9} (Edu.Inc). Therefore, today's middle school students do not demonstrate an adequate understanding of concepts of scale and size on the micro and the nano level (Tretter, Jones, Andre, Negishi, & Minogue, 2006). Students are unable to identify the relative sizes between micrometer-sized and nanometer-sized objects (Edu.Inc, n.d., 2004, 2005; Holladay 2005; Jones et al. 2004; Waldron, 2006).

In addition, surveys demonstrate that there are high levels of unawareness and misconceptions in relation with nanotechnology and nanoscience. Research also suggests that some students have difficulties in understanding the concept of atom. In particular, students have trouble understanding the particle nature of matter and have misconceptions about the relative sizes of atoms, molecules, viruses, cells, bacteria, etc.

They are not able to distinguish between the micro and nano world. These results can further be corroborated with research done by Ben-Zvi, Eylon, and Silberstein (1986a), and Krajcik (1991), who found that students hold a continuous model of matter and assume that a single atom carries properties of the substance or material. The discovered results were similar in a more recent study done by Nakhleh, Samarapungavan, and Saglam (2005). They have found that although students knew that matter was composed of atoms and molecules, the middle school students could not be classified as having consistent knowledge frameworks because their ideas were very fragmented. They found that some students had the conception that they could see atoms or molecules under an optical microscope in the same way they could see microbes. Their data also indicate that it was difficult for students to view solid, nongranular matter as being composed of particulate or molecular matter.

A strategy to address this problem is proposed by Edu.Inc (2005). They argue that in order to understand the concept of nanotechnology, first it is necessary to understand the word 'nano,' appreciate that there is a measure called 'nanometers,' understand the scope of 'billion,' and finally, know what a meter is. Researchers at Edu.Inc add that to fully understand nanotechnology students must also understand terms such as 'matter,' 'atoms,' and 'molecule.' Moreover, students must grasp that a sub-visible size scale exists in the first place, that sub-visible objects exist in different sizes, and that scientists can manipulate matter that they cannot see.

Linn, Clement, Pulos, and Sullivan (1989) also found that topic-related training enhanced knowledge about relevant variables and resulted in reasoning changes. In the same way, Nakhleh et al. (2005) explained that students form naive frameworks at an

early age based on their experiences, and eventually these frameworks are modified by exposure to formal instruction. This research shows that a child can be taught any abstract concept. It only depends on the adequate formal instruction together with the integration of previous knowledge as well as addressing misconceptions and naive conceptions.

Critical aspects for teaching nanoscale to middle school students

It has been identified that middle school students may require abstract thought in order to understand the concept of nanoscale (Eylon & Linn, 1988; Inhelder & Piaget, 1958). Therefore, the learning theories that address specifically issues related to abstract thinking are the developmental genetic epistemology of Piaget, and the alternative theories of cognitive development.

The developmental perspective relates to when in the life span students attain scientific concepts (Eylon & Linn, 1988). According to Piaget's cognitive development stage view (Inhelder & Piaget, 1958), young children are different kinds of learners and thinkers than adults. Until they reach the age of 12 or so they are not capable of reasoning as an adult and show abstract thinking. The theory of cognitive development proposed four major stages of development: the sensorimotor stage, the preoperational thought stage, the concrete operations, and the formal operations.

Our target audience would be at the beginning of the formal operations stage; this same stage continues to adulthood. The characteristics of this stage are that persons are capable of thinking logically and abstractly. They can also reason theoretically. This means that in this stage children are capable to generate abstract propositions, multiple hypotheses and their possible outcomes are evident. Thinking becomes less tied to

concrete reality (Inhelder & Piaget, 1958).

The alternative theories of cognitive development build upon Piaget's genetic epistemology. These alternative theories incorporate elements of the cognitive information processing perspective. Case (1993) suggested that the mental space, a concept similar to working memory, increases during development. He suggested that this increase occurs because of three processes: brain maturation and its resulting myelinization that increase processing speed, cognitive strategies become automatic, and prior knowledge becomes more extensive and better organized (as cited in Smith and Ragan, 2005). This view proposed that it is the process of encoding that distinguishes cognitive development.

An important aspect to consider is the role of experience in specific domains. This aspect was deeply studied by Siegler (1983, as cited by Driscoll, 1994). He was focused on local description as well as on specific task requirements. He suggested that when the role of encoding was emphasized, it resulted in children's construction of more advanced knowledge. Siegler (1994, as cited by Driscoll) developed a performance model for problem solving. He incorporated four steps consisting on children actively encoding the features of a problem by trial and error, monitoring these features and selecting specific rules ad hoc to the problem. Then, combining the dimensions into the rule, and executing it correctly.

A study conducted Linn et al. (1989) corroborates the role of experience in scientific domain. These researchers assessed the role of science topic instruction combined with logical reasoning strategy instruction in teaching adolescent students. They found that topic-related training enhanced knowledge about relevant variables and resulted in reasoning changes. This suggests that reasoning strategies and knowledge of

the subject matter influence abstract thinking. This improvement results from student's restructuring of their naive frameworks modified by exposure to formal instruction (Nakhleh et al., 2005), and as individuals learn a new domain of science (Carey, 1986).

Eylon and Linn (1988) considered the important role that working memory capacity plays. They suggested that adequate instruction, together with learners consolidation of information into procedures, would result in learners becoming able to handle more complex problems using the same amount of processing capacity. Ben-Zvi et al. (1986a) also proposed that abstract reasoning may vary as a function of working memory demand rather than development, and therefore, if a given problem overloads working memory, students cannot reason abstractly and revert to a more concrete approach. One way to reduce this overload of working memory is by using instructional strategies that will help address misconceptions.

Another common problem in learning science is the conceptions that students may have of scientific phenomena that rarely coincide with those of expert scientists. Therefore "students lack ability to relate science studied in school to naturally occurring problems" (Songer and Linn, 1987, as cited in Eylon and Linn, 1988). Research tells us (Ben-Zvi et al., 1986a; Cocking, Mestre, & Brown, 2000) that it is something natural that a student can have previous conceptions about a certain phenomena. Some of them can be right, some of them can be incomplete and some of them can be wrong. Therefore, and as stressed by Strike and Posner (1992), these previous conceptions are part of the learner's conceptual ecology and they must be seen in interaction with other components.

Logical sequences of concepts are often not enough to change misconceptions. Students also need opportunities not only to build new explanations by developing models,

thinking about analogies and conducting experiments, but also to relate these new concepts with their previous knowledge (Carey, 2000). Students need to become aware of their misconceptions and naive conceptions and then modify their frameworks in the light of the formal instruction they have received (Nakhleh et al., 2005). For this, it is required to incorporate the learner's way of looking at the world in the development of concepts. Stepan (1991) suggests that we need to (1) identify the naive conceptions held by learners, and (2) decide on proper time and effective methods to remove those conceptions. And not only remove those conceptions, but also transform their naive ideas into more sophisticated scientific understanding, to change incorrect concepts, and to develop mental structures for unfamiliar concepts (Cocking et al., 2000).

Therefore, abstract thought is required for conveying the concept of nanoscale. Although Piaget concluded in his studies that young learners cannot show abstract thinking until they reach the formal operations stage, the alternative theories of cognitive development argue that students appear quite able to think abstractly as long as they have appropriate science knowledge of the subject matter, even if they are young and if their ideas are incomplete. Therefore, deep coverage of the topic may elicit abstract reasoning (Eylon & Linn, 1988). Thus, in order to overcome the limits of working memory capacity it is necessary to help students in their process of encoding and automatization. This could be done by adequate topic-related formal instruction, knowledge of the subject matter, reasoning and reflective strategies, feedback for self-monitoring, and integration of the new information with prior knowledge.

Level of attainment of the concept of nanoscale

Ausubel et al. (1978) defined concepts as "particular sets of objects, events, symbols, properties, or situations that can be grouped together on the basis of one or more shared characteristics and are given a common identifying label or symbol" (as cited in Newby and Stepich, 1987, p 20.). Complementing this definition, Klausmeier (1990) makes a distinction between concrete concepts and abstract concepts. He explains that concepts that have attributes that are readily observable can be classified as concrete, and in contrast, at the abstract end of the continuum, are concepts that have verbal attributes. According to this definition, then the concept of nanoscale can be described as an abstract concept because its attribute(s) is (are) intangible.

For defining the adequate level of concept attainment for nanoscale, the framework used was Klausmeier's theory of concept development. The theory of concept development iterates principles of learning and development. According to Klausmeier (1990), this theory describes how a given concept is attained at four successively higher levels of understanding. The theory also specifies the cognitive processes involved in attaining each level of the concept, indicates the uses made of the concept when attained at each level and specifies the instructional conditions that facilitate learning at each level. There are four levels of understanding in which a concept can be attained, as described in Table 1.

Table 1: Klausmeier's levels of concept attainment.

Level	Description
Concrete level	A concept is attained when an item is discriminated as an entity different from its surrounds and then later is recognized as the same entity when still in the same spatial orientation or other context.
Identity level	Attainment of a concept at the identity level is inferred when the individual recognizes an item as the same one previously encountered when the item is observed in a different spatial orientation or other context.
Classificatory level	This level of a concept is attained when two or more examples of the concept are generalized as equivalent.
Formal level	At this level the concept is attained when the concept is identified and its attributes are named, a definition of the word is provided in terms of its attributes and can classify examples from non-examples.

By analyzing the target audience and referring to the Project 2061's benchmarks of the American Association for the Advancement of Science (AAAS) and National Assessment of Scientific Progress (NAEP) of the Institute of Education Sciences of the U.S. Department of Education, it was identified that between grades 6 through 8, students are starting to get familiar with very large and very small numbers, ratios, and working with powers of ten.

The benchmarks also emphasize that "understanding the notion that things necessarily work differently on different scales is more difficult than recognizing extremes, hence students should study a variety of different examples" (AAAS, 2006). It is on grade 9 through 12 when students experience a facility while using powers of ten and therefore can make it easier to describe great differences of scale, but not necessarily to make them comprehensible.

In addition, and according to the science section of the National Assessment of Sci-

entific Progress (NAEP, 2005), at grade 8 in 2005, 59% of students scored at or above the *basic* level and 29% of eighth-grade students performed at or above the *proficient* level. From descriptions provided by the National Assessment of Scientific Progress, it is only at the *proficient* level when students at the end of their middle school have an emerging understanding of the particulate nature of matter, and at the *advanced* level have a *modest* understanding of scale (NAEP, 2005). Therefore, the level of attainment for the concept of nanoscale for middle school students was considered as acceptable if attained at a *concrete level*.

The cognitive processes required to attain a concept at the concrete level described by Klausmeier (1990) are:

- Attending to an item.
- Discriminating the item as an entity different from its surrounds on the basis of one or more of its defining attributes.
- Representing the item in long-term memory.
- Attending to and discriminating the item at a later time.
- Retrieving the representation and using it in recognizing the item as the same entity discriminated earlier.
- Storing the concrete level representation in long-term memory and being able to retrieve it.

The instructional materials were designed to address these cognitive processes in order to attain the concept of nanoscale at the concrete level.

Learning strategies for conveying molecular theory related concepts

Literature suggests the following instructional strategies as being proved to be successful in teaching the concepts of atoms and the particulate nature of matter in formal settings.

- Integration and differentiation. Integration that consists in linking consistent but unrelated conceptions and differentiation that consists of highlighting the differences between related concepts,
- analogies and metaphors to develop conceptual understanding,
- models for explaining something that is not familiar, and
- computer visualizations and simulations to represent the dynamic nature of the concepts.

We discuss how these strategies have been or could be incorporated in teaching the concept of nanoscale.

1. Integration and Differentiation.

A good way to address misconceptions is by creating a situation of cognitive dissonance leading to greater accommodation. In that way, the epistemic transition from one conceptual scheme to another could be facilitated (Eylon & Linn, 1988; Kitchener, 1992; Novick & Nussbaum, 1978). By creating a situation of conflict, a process of reflection may be elicited. Integration and differentiation are useful strategies that create a situation of conflict, and at the same time elaborate connections among ideas. These cognitive processes may result in more robust conceptual structures and avoidance of mixture of related concepts and discrimination between them (Eylon & Linn, 1988). According to

Hewson and Hewson (1984, as cited in Eylon and Linn, 1988), integration links consistent but unrelated conceptions. Such linkage increases the likelihood that scientific knowledge will be remembered and facilitates reasoning. On the other hand, differentiation identifies differences between related concepts.

A successful implementation of these techniques was carried out by Ben-Zvi et al. (1986a) in a chemistry course that was designed to assess the students' previous knowledge and at the same time to make the students aware of their misconceptions. In this implementation Ben-Zvi et al. presented the concept of an atom as an ever-evolving model, and as a result fewer students developed the misconception that an atom is a small portion of the material with the same characteristics and properties as the macroscopic one. Therefore, these two strategies are a good starting point to consider the previous knowledge and assess and/or correct the misconceptions, if any.

2. Analogies and metaphors.

Nersessian (1992a, 1992b) suggests that in order to help learners create abstractions from existing conceptual structures it should be implemented what she calls *abstraction techniques*, which consists of specific heuristic procedures such as analogies, thought experiment, limiting case analysis, and reasoning from imaginistic representations. The great advantage that analogies provide is that it is a very good way for addressing previous knowledge. They provide a method for students to become actively involved in constructing meaningful knowledge by linking previous knowledge to new concepts and restructure their conceptual understanding (Krajcik, 1991). In addition, analogies and metaphors are useful for explaining abstract science concepts in a familiar way, and when combined with models provide visual and even tactile ways of

representing the phenomena (Harrison & Treagust, 2000).

Exhibits at It's a Nano World are mainly composed of analogies together with models. "Models in the context of It's a Nano World indicate object that represent sub-visible items (e.g. ball representing cells and pinballs representing dust, germs or pollen)" (Edu.Inc, 2004). The analogies together with the models served as a way of scaffolding to the visitors. The analogies represented with models used in this exhibit resulted in delivering a basal primer of concepts needed to build background for future understanding (the macro-to-micro connection), but they did not successfully make the micro-to-nano connection.

3. Models.

It has been documented (Lehrer & Schauble, 2000; Nersessian, 1992b) that experts use visual imagery like models as well as graphs, symbols and other representational systems to help them represent and understand problems and facilitate solutions.

Mayer (1992) describes a model as a representation that involves the envisionment of a principle-based mechanism with interacting components that represent the functionality or operation of a portion of the natural world and that may also concretize phenomena that are not directly observable. This technique is useful when it is required to emphasize explanations.

A model can not only be useful for abstracting from phenomena but also can help children extend their naive use of models into complex multifaceted applications (Cocking et al., 2000). However, model-based instruction must be handled carefully. Research has found that sometimes at the moment a model is used for representing

something that is not familiar or cannot be seen in terms of something that is familiar or visible, children can misunderstand that the model is only a representation and actually learn the model itself. Renner and Marek (1988) stated that “In presenting concrete learners with abstract concepts such as models of atoms and molecules, what learners learn are the models rather than the concept they represent.” (as cited in Stepan 1991). A good way to avoid this problem is when instructional materials cover multiple rather than isolated models (Harrison & Treagust, 2000).

This strategy is used at the exhibit of nanotechnology at Discovery World Museum to help individuals understand the size and scale of nanotechnology and how to measure structures at this size (Holladay, 2005). The main feature used for this exhibit is the hands-on exhibit based on inquiry based learning. Results from the formative assessment show that the students and adults were able to develop a deeper understanding of advanced materials concepts and were able to learn and apply the concepts contained within the exhibits (Castellini et al., 2005).

4. Computer visualization and simulation.

In the last decade the use of computer visualization and simulation tools have resulted in a deeper understanding of the particulate nature of matter. The obvious advantage of the above mentioned techniques is the dynamic representation of the phenomena. This strategy, combined with analogies, models, etc., can result in significant understanding of abstract concepts and for its retention (Sabelli, 2006).

”This methodology is so important that it has become common in scientific discourse to consider mathematical experimentation or experimental use of computer simulations as a third leg in the triangle by now commonly used to

describe the late 20th-century methodologies of science; theory and physical experimentation is no longer suffice.” (Sabelli, 2006)

Nakhleh et al. (2005) propose that the use of visualization tools and simulations together with a wider range of examples will result in a deeper understanding because in this way the phenomena are represented in a dynamic way. This increased understanding may be due to the superiority of the formation of more expert-like, dynamic mental models of a more detailed view of atomic and molecular behavior (Williamson & Abraham, 1995).

For showing the concept of size and scale, NanoZone and Marvelous Molecules have used simulations such as the zoom technique. NanoZone have used it to show magnified familiar objects, while Marvelous molecules have used it to zoom molecular structures. Edu.Inc (2005) reported that at NanoZone were evidence of visitors’ learning behavior, content acquisition, and changing attitudes, and revealed that the majority (at least 75 percent) of visitors deepened their understanding of at least one of the main content themes of the exhibition. Nonetheless, visitor comments show that significant misconceptions and partial understanding remain in visitors’ understanding of nanotechnology and other content areas after using the exhibition. This evaluation showed that a majority of visitors improved their understanding of size at the nanoscale. There was little evidence that children or adults gained an understanding of the comparative size and scale of sub-visible objects (Edu.Inc, 2004).

In the case of Marvelous Molecules, Serrell and Associates (2001) found evidence of students recalling the big idea, as well as remembering many specifics about the individual elements. They also found that the concepts may not be comprehended by a

majority of children under 12 and some of the adults.

From all these strategies, we have selected analogies and metaphors as the vehicle to convey the learning goal.

Analogies and metaphors as the learning strategy

Analogies and metaphors are fundamental cognitive mechanisms that people use to map processes by identifying relevant information from a more familiar domain to a less familiar one (Mason, 2004). It also enables people to infer about novel phenomena, as well as to transfer learning across subject domains (Gentner and Markman, 1997; Goswami, 2001; Richland, Morrison, and Holyoak, 2006).

While analogy is a sophisticated process used in creative discovery, similarity is, as described by Gentner and Markman, (1997), brute perceptual process. Gentner (1983) define an analogy as “a device for conveying that two situations or domains share relational structure despite arbitrary degrees of difference in the objects that make up the domains. This promoting of relations over objects makes analogy a useful cognitive device, for physical objects are normally highly salient in human processing” (as cited in Gentner and Markman, 1997, p.46). They emphasize the importance of common relations to analogy and not common objects. In contrast, English, (1997) describes metaphors as characterized by cross domain mappings. She explains that reasoning by metaphor implies conceptualizing the phenomena in terms of another mental domain by finding a mapping between the target domain and the source domain. ”Like analogical reasoning, metaphorical reasoning can generate new inferences and lead to the construction of mental models based on the relational structure shared by the source and target.”

(English, 1997, p.7).

Analogies and metaphors therefore may serve as an adequate strategy for scaffolding the required students' cognitive process for attaining scale cognition. Tretter et al. (2006) describe this cognitive process as a process of unitizing. Unitizing is described as a way for creating new meaningful units from the existing objects. Tretter et al. also suggest that students must create scale mental models focusing on relative sizes and not much on exact size information. These mental models could be based on everyday uses and conceptions of size with categorical relations. In addition, Tretter and his colleagues (2006) also suggest that conceptions of scaling must be based on experience, be organized into categories and may contain prototypes as exemplars of categories; such as landmarks and reference points.

These remarks pointed us to consider Rosch's prototype theory of concept learning. According to Rosch (1975, 1978) a concept is learned and represented as a prototype of a class of objects. A prototype of a class is an image constructed from experiences with examples of the class. The prototype includes the typical features of the class, not all of the defining attributes as the classical theory. After a prototype is formed, newly encountered instances are identified by comparison with the prototype (as cited in Klausmeier, 1990). Therefore, and as stated by (Newby & Stepich, 1987), a good way to facilitate the learning of an abstract concept would be to generate a reasonable substitute for a prototype by first transforming the attributes of the abstract concept into a more concrete form. As a result, a prototype substitute will be generated and provide a mental model based on everyday uses and conceptions of size. This prototype [analogy] is a sense-making way to unitize for making scale comparisons (Tretter et al., 2006).

From the above findings it can then be argued that scale related concepts are abstract and therefore difficult to convey at a middle school level. A proposed solution can be based the alternative theories of cognitive development, which considers that students are capable to think abstractly if limits of working memory can be overcome by appropriate science topic-related formal instruction, knowledge of the subject matter, reasoning strategies, integration of prior knowledge, and feedback. Therefore, the research question is:

Will middle school students, after being exposed to formal instruction based on cognitive information processing theory, be able to convey the relative sizes between microscale and nanoscale objects?

Method

Design of the instructional materials

The instruction was structured in the following way. In order to provide a context of the concept of nanoscale, learners were first required to be introduced the concepts of nanoscience and nanotechnology. For this purpose, learners had to recall the difference between science and technology by pointing out that technology refers to the application of scientific advances while science refers to the use of the scientific method in order to derive systematized knowledge.

Then, for adequate comprehension of the new concept, prior knowledge had to be provided. Learners might require identifying the difference between size and scale, and recalling that all matter is made up of atoms and that atoms bond together to form molecules.

Once provided the structure, the instruction required to continue by the instructor explaining the new information using the adequate learning strategies, and the students carrying out exercises and creating their own knowledge by interacting with their peers. The process that the learners had to experience was designed as follows: 1) the learner identified that nanoscale refers to objects and particles that are too minuscule to be seen through a light microscope, instead of seeing them, we have to sense them with very powerful probe microscopes. 2) the learner identified that nanoscale objects are different from microscale objects, 3) given examples of macro, micro and nano sized objects; the learners classified them in micro sized objects, nano-sized objects and atomic-sized objects, 4) and finally, given macro-sized, nano-sized, and micro-sized objects, the learner made scale comparisons of these objects and ordered them.

For attaining the learning goal, an instructional design theory based on the cognitive information processing perspective was required. Therefore Gagne's theory was selected to develop instructional materials focused on intellectual skills. The instructional design based on Gagne's theory embedded and supported the learning strategy for conveying the difference in relative sizes between microscale and nanoscale objects. This theory incorporates a taxonomy, specific learning conditions, and nine events of instruction (Driscoll, 1994). In Gagne's taxonomy of learning outcomes, concepts are classified among the intellectual skills. According to Gagne, intellectual skills can be divided into five categories organized in a learning hierarchy. Our focus will be on the second type of intellectual skills, the concrete concepts, which consists of classifying new examples of events or ideas by their defining attributes. Gagne's nine events of instruction were implemented as described in Table 2.

Table 2: Structure of the materials based on Gagne's nine events of instruction

Event	Implementation process
Gaining attention	The topic was introduced by emphasizing the importance of nanotechnology. It was also described that thanks to new tools and techniques scientists are able to study it. Some interesting applications of nanotechnology were also mentioned.
Informing the learner of the objective	It was described that the goal of the instruction was to understand the basic tenet of nanotechnology, which is the concept of nanoscale. It was also described the difference and relationship between nanoscience, nanotechnology, and nanoscale
Stimulating recall of prior knowledge	Two main topics were recalled in this event. Students were elicited to recall the role of atoms and molecules and conversion procedures between feet and meters. This eventually led to conversion from meters to nanometers
Presenting the stimulus and providing learner guidance	The difference between macroscale and microscale was emphasized. Then, the analogies with the metaphor were presented.
Eliciting performance and providing feedback	A sorting activity was presented. Learners classified several objects according to their scale (micro, macro, or nanoscale). Feedback was provided.
Enhancing retention and transfer	The learner was involved in a collaborative activity consisting of creating their own analogies. A strategy for creating analogies was presented to the learners and guidance was provided during the elaboration process.
Assessing performance	For assessing performance, the student was asked to sort and order the objects in the scale. Feedback was provided.

The instruction required to provide learning and cognitive strategies in the form of those used for basic learning task that tie new information to prior knowledge; namely analogies and metaphors. Therefore, the analogies were used to scaffold the unitizing cognitive process that according to Tretter et al. (2006) is the first required cognitive process in order to attain scale cognition. This strategy created new meaningful units from the existing objects involving a proportional relationship (e.g. the difference in sizes between the height of a human and the length of an ant is approximately the same–

proportional as the difference in sizes between a bacteria and the diameter of a DNA double strand).

In addition, a scale was used as a metaphor to represent powers of ten, that is, powers of ten were considered as points on a line. This scale was used to display number sequences and scales: macroscale, microscale and nanoscale. (see Figure 2). This scale provided a graphical aid for unitizing and categorizing. Proportional analogies together with the scale metaphor were used as a way to explicitly compare two things in which their relational structure; namely their proportional sizes were emphasized.

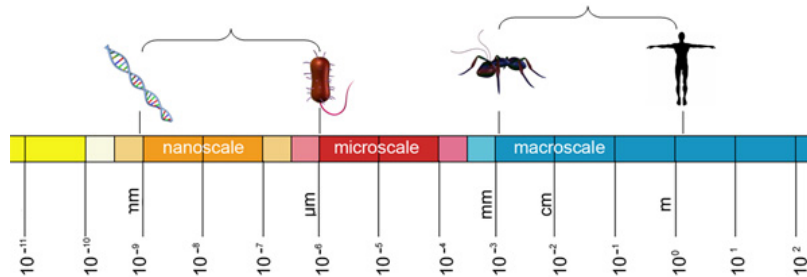


Figure 2. Example the scale metaphor and proportional analogies for conveying the relative and absolute sizes of macroscale, microscale, and nanoscale objects.

Sample

The delivery of the instructional materials was conducted in a 7th grade science class at a mid western middle school. The population of the seven graders at the middle school is approximately of 170 and from those, 130 were exposed to the instructional materials. This group of students was identified by the school corporation and by the seven graders science teacher. Therefore, the instructional materials were presented in an established educational setting and took place as part of normal educational practices for this group of students. From these 130 students 110 completed all the set of activities and assessments as well as the two days instruction. The purpose of this evaluation was to determine the effectiveness of the materials, ascertain any problems that might arise in

the administration of the materials in a real instructional environment, and validate the instruction with a large enough sample of the target audience to make a confident prediction of the effectiveness of the instructional strategy. In addition, 44 students were evaluated after being exposed to an informal learning environment.

Instruments

For assessing student's knowledge prior instruction, an instrument was developed. The first section consisted of ordering a group of nine objects from smallest to biggest (ordering activity). The second section asked the students to classify in three bins a group of 11 objects according to similar sizes (classifying activity). This section also asked the students to label each bin according to their classification. The purpose of this instrument was to first know if students were familiar with the relative sizes of objects, to know if students had a consistent idea of the atom as the smallest object they know, and if students had a consistent notion of scales or worlds and objects that were similar in sizes.

Two more instruments were designed to be applied after instruction. The instrument that was applied after the first day of instruction consisted of objects to be classified in three bins labeled as nanoscale, microscale and macroscale (classifying activity). The purpose of this instrument was to know if instruction was effective in conveying objects belonging to different scales. The last instrument developed consisted on ordering 11 objects using this time the scale used during instruction. The purpose of this instrument was to know if instruction was effective in conveying the relative sizes between objects together with its classification (ordering activity). In this particular exercise, three new objects were introduced, two of them were the atom and a water

molecule to assess if student's understanding of the particulate nature of matter was still consistent.

Although the validity of the instruments was determined by expert judgment, after the field trial there were found two threats to the validity of the instruments. In the instrument applied prior instruction it was found that there were unclear test directions. In the instruments applied after instruction it was observed that students got confused with untaught items included in the test.

Procedure

The implementation process consisted on first getting in contact with the science teacher in charge of delivering the instruction. The researcher together with the teacher reviewed the instructional materials and the result was some modifications to the materials to fit with her teaching style. Once the science teacher got comfortable with the instructional materials, the in-class instruction was conducted. The instruction was delivered during two days consecutive one hour classes.

In order to assess student's knowledge of sizes of objects, one day before the delivery of the instruction, students were asked to solve the first exercise. During the first day the instruction was delivered with the teacher explaining the concepts and the students participating in the discussion. Whenever possible, the teacher made the materials more familiar to the students and connected the content with topics they had covered in class. The scale metaphor was presented together with a conversion exercise from meters to nanometers in order to help students get more familiar with the artifact – the scale. After that, the analogies together with the scale metaphor were presented and

the teacher scaffolded each of the four analogies and students participated by answering the verbal cues the teacher presented. With each and every analogy the teacher emphasized the relative sizes of the objects and students were elicited to say how many times an object was smaller or bigger than the other. The first day instruction concluded with about two to three minutes for solving the classifying objects exercise.

For the second day of the instruction students worked with their teams in creating their own analogies. After interacting for about 20 minutes, then the group got together again and each team shared their work with the rest of the class. Immediately after that, the final assessment was administered. The researcher carried out the evaluation of the activities/assessments.

Analysis

For evaluating the ordering activity, the pair wise comparison technique was used and for evaluating the classifying activity points were given per each object classified correctly. The last exercise was evaluated twice, the first time considering how students ordered the objects using the pair wise comparison technique, and the second time assessing the classification of objects.

Since the assessment instruments were not designed to be compared among them, adjustments were required. Only the same objects among the instruments were used for comparison purposes. Descriptive statistics were used to describe and summarize the data.

Results and discussion

The evaluation results showed that the instructional materials improve students' ability to classifying objects according to their scale. Thus indicates the students can

identify the difference in relative sizes between microscale and nanoscale objects. The results also showed that student's performance could be improved with the following changes. First, the atomic scale should be included in the main section of the instruction; namely the inclusion of the atomic scale in the scale metaphor and an analogy for addressing objects at the atomic scale. Second, the instruction must identify both the similarities between the objects (i.e. proportional relationship), and the relative difference between pairs of objects. Finally, learners require more opportunities to practice applying these concepts and receive feedback on their performance.

During the first sorting exercise prior to instruction, only 44% of the students showed a consistent idea as the atom as the smallest object. For this particular item, the sample was then divided into two groups in order to assess their progression; students who reported the atom as the smallest object (44%) and students who did not report the atom as the smallest object (56%). From those students who did not select the atom as the smallest, 64% improved their performance by selecting the atom as the smallest object after receiving the instruction. On the other hand, from the 44% who selected correctly the smallest object, only 47% repeated their correct selection. This could be because of the introduction of new objects in the after-instruction assessment. It could also be that the contrast of objects in the exercise prior instruction was clear, however, when they were faced with the nanotube and molecule they no longer thought of the atom as the smallest object showing fragmented ideas.

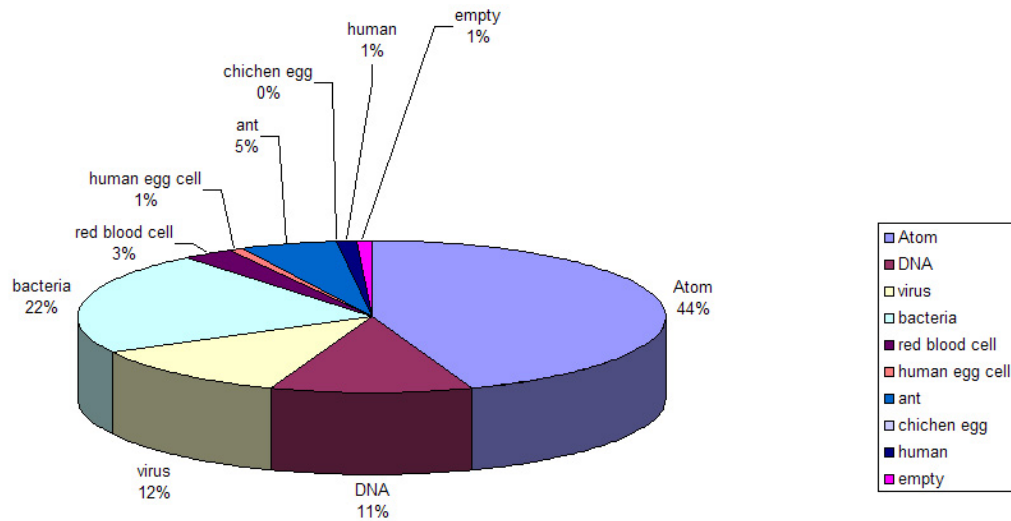


Figure 3. Smallest object selected by the students during the exercise prior to instruction

The results from the exercise prior to instruction were used to make groups.

Group 1 is the 59% of students who classified the objects by size. Group 2 are students that did not classified by size. Group 3 are students who did not receive the instruction based on analogies and metaphors, but were exposed to an informal learning environment (see Figure 4).

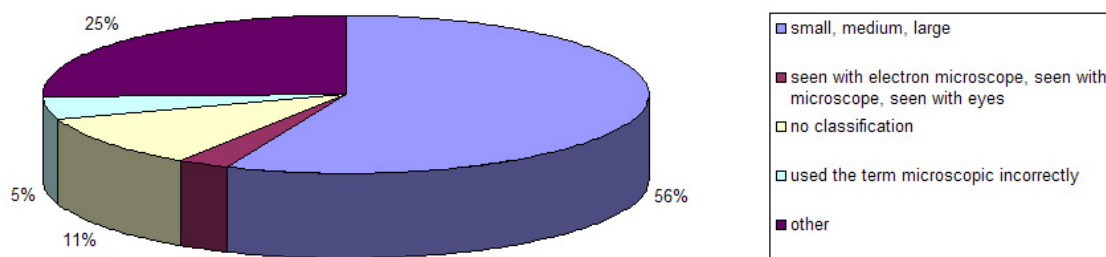


Figure 4. Classifications proposed by the students before instruction

The performance of the three groups in the classifying activities is described in Figure 5 and in Table 3

Figure 5. Performance in the classifying activities

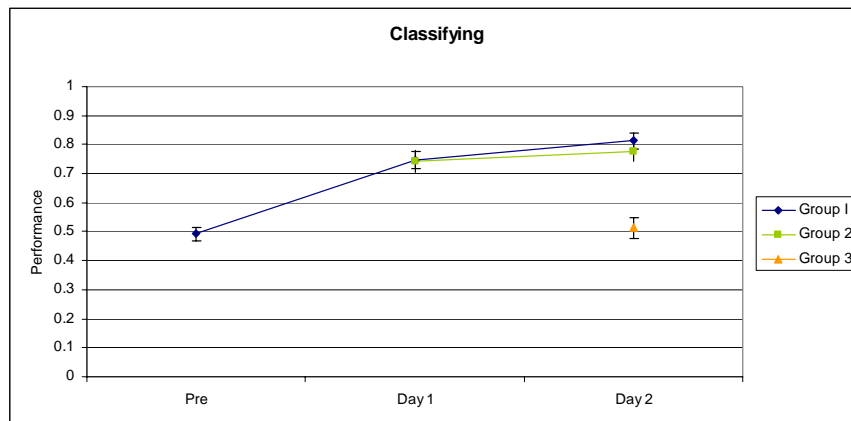


Table 3: Means and standard deviations in the classifying activities

	Classified by size 59% (group 1)	Other classification 41% (group 2)	Informal learning env. (group 3)
Prior instruction	μ 0.49 σ 0.02		
After first day of instruction	μ 0.75 σ 0.03	μ 0.74 σ 0.04	
After second day of instruction	μ 0.81 σ 0.03	μ 0.78 σ 0.04	μ 0.51 σ 0.04

The performance of the three groups in the ordering activities is described in Figure 6 and in Table 4.



Figure 6. Students' performance in the ordering activities

Table 4: Means and standard deviations in the ordering activities

	Classified by size 59% (group 1)	Other classification 41% (group 2)	Informal learning env. (group 3)
Prior instruction	μ 0.86 σ 0.02	μ 0.83 σ 0.03	
After second day of instruction	μ 0.92 σ 0.02	μ 0.91 σ 0.02	μ 0.41 σ 0.01

In addition, classroom observations were conducted. The researchers focused on how the teacher scaffolded the content to the students, student's attitudes and reactions about the topic, as well as to ascertain any problems that might arise in the administration of the materials in a real instructional environment. It was observed that found that students showed a positive attitude towards the content, and identified that student's got the most excited when the applications of nanotechnology were presented by the instructor.

Conclusion

In the final analysis, it can be concluded that in order to meet the future needs in the nanotechnology field, we have to start by raising the level of awareness at a middle school level and continue by getting students interested in the field, and by conveying the underlying concepts of nanotechnology and nanoscience. Scaling related concepts have been identified as common tools between disciplines and levels as well as important unifying topics in science, engineering, and technology education.

For this reason, instructional materials were developed in order to convey the relative sizes between microscale and nanoscale objects. These materials were based on Gagne's theory and theory of concept development. In addition, analogies were selected

as the vehicle to convey that two pairs of objects share a relational structure; namely their proportional sizes. In addition, a scale metaphor was used to represent powers of ten as points on a line.

Together, these two strategies served as an adequate scaffold to student's cognitive process for attaining scale cognition.

After instruction, students exposed to analogies and metaphors improved their performance in classifying objects and ordering objects. Analogies and metaphors may serve as an adequate scaffold to student's cognitive processes for attaining scale cognition.

The limitations of this study are: a) the fact that only one teacher delivered all the instructional materials, b) the assessment instruments were not designed to be compared among themselves and therefore some adjustments were required for comparison purposes and c) the data was just analyzed descriptively and a more rigorous statistical analysis may be required.

Future work includes the elaboration of a more formal study using qualitative and quantitative methods to get detailed information about student's progression in their conceptions of scale as well as their consistent and/or inconsistent understanding of the particulate nature of matter. Another interest of the researchers is to investigate how proportional analogies may scaffold the student's logical and mathematical conceptions of scale. This can include a longitudinal study in which later on the scaffold can be removed.

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