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Identification of Misconceptions Related to Size and Scale through a Nanotechnology-Based K-12 Activity

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Abstract

Nanoscale science activities are filtering into K-12 classrooms in part due to modern technological advances in the areas of healthcare, electronics, and renewable energy. These industries benefit from scientists who possess a deep understanding of science at the nanoscale and it is well known the United States needs to increase its STEM educated workforce to stay globally competitive. Nano-related activities can be effective in motivating students to pursue careers in engineering and technological fields, but at the same time they are useful in helping to pinpoint common misconceptions that exist in K-12 science classrooms. In this study, an inquiry-based lesson on the topic of surface wettability was implemented in three magnet high school classrooms. Students were asked to measure the contact angle of a water droplet on transparent glass surfaces with varying degrees of wettability (hydrophilic, hydrophobic and superhydrophobic). Based on their observations and angle measurements students were asked to write a description and make a sketch of what they thought the surface structure would look like under a microscope. Qualitative analysis was done to analyze students' drawings and written descriptions. Students' responses were grouped into topics to identify patterns related to the high school curriculum taught in chemistry, biology and physical science.

Most students determined the surface coatings were different enough from each other to cause the water droplets to either bead up or spread out on the surface. The drawings of what the coating structure would look like under a microscope were varied but some depicted atomic level repulsive/attractive forces surrounding the water droplet. This highlights a common misconception about what can actually be seen and not seen under a microscope. Students also repeatedly attributed the shape of the droplet to positive/negative charges rather than surface tension. This can possibly relate to not comprehending the existence of varying length scales between the atomic and macro scales. In summary, the presentation will discuss how inquiry-based activities on the topic of nanoscale science can serve to identify misconceptions in science classrooms and guide instruction in this area.

Introduction

Various efforts exist to teach nanoscale science & engineering (NSE) content at the undergraduate level [1, 2] and there is a growing NSE education community that is developing lessons and activities specifically designed for K-12 educators [3]. Nanoscale science has been recognized as truly interdisciplinary and oftentimes reflects modern science better than the traditional science disciplines [4]. Previous reports demonstrate that introducing NSE modules in a high school engineering classroom can leave students with positive perceptions about nanotechnology [5] and allows students to delve into science content across multiple size scales [6]. Furthermore, just having a firm understanding of what objects look like at the nanoscale can help students gain a better understanding of concepts in related scientific fields [7].

On the other hand there are challenges in implementing NSE lessons into an already packed science curriculum. Summer programs can offer an alternative route to introduce topics of interest but the one-to-two week structure makes it difficult to cover enough content to enable a deep transfer of knowledge. During the school year, nanoscale science modules are short or do not fit in with the rest of the science curriculum. Even when they are introduced as curricular units, the fundamental science concepts can be lost in the novelty of the activity. Schank et al reported on how some nanoscale science units were difficult to understand even though they were effective at engaging students [6]. Lessons can also be too abstract or require substantial review of basic concepts from chemistry, biology and the physical sciences. Naturally, some questions arise: What is an effective way to implement an NSE lesson, what content can be learned from an NSE activity and what misconceptions do NSE lesson reveal about fundamental science concepts?

In 2007 the National Science Foundation identified nine “big ideas” that would help science educators teach lessons in the area of NSE. These ideas included: 1) Size and Scale, 2) Structure of Matter, 3) Forces & Interactions, 4) Quantum Effects, 5) Size-Dependent Properties, 6) Self-Assembly, 7) Tools & Instrumentation, 8) Models & Simulations, and 9) Science, Technology & Society [7]. The first three ideas are considered to be foundational science content areas and they correlate well with disciplinary core ideas in the physical sciences and life sciences as described by the Next Generation Science Standards (NGSS) [8]. In addition, they match closely to three of the cross cutting concepts found in NGSS: 1) scale, proportion and quantity, 2) energy and matter and 3) structure and function. Furthermore, as will be shown in this study, an NSE lesson can be a formidable way to model science and engineering practices, especially if it is presented as inquiry where students have to design and carry out their own investigations and defend their explanations.

In this study, an inquiry-based NSE activity was conducted in three high school STEM classrooms on the topic of surface wettability. Student sketches and reflections were collected and analyzed to gauge how students interpreted NSE foundational content. The frequency of depictions related to the first three foundational content areas were recorded as well as how often an idea related to biology, chemistry and physical science.

Description of Activity

The NSE activity was an adaptation of an undergraduate laboratory on measuring contact angles on hydrophobic surfaces [9]. It was implemented in three magnet public high schools classrooms where students were in their junior or senior year. The classes were electives in advanced physics, an introductory course to chemical engineering and an introductory course to aeronautical engineering. The concept of surface wettability was briefly introduced in each class through a class discussion highlighting commercial products that are able to repel water or have self-cleaning properties (e.g. Teflon, Rain-X, etc.). The development of some of these products was inspired by nature [10] and are dependent on a coating that was designed to repel water. Students were placed in groups of four and then given three pre-prepared transparent glass surfaces with varying degrees of wettability (hydrophilic, hydrophobic, and superhydrophobic). The hydrophilic surface was a plain microscope glass slide with no coating. The hydrophobic surface was a microscope glass slide coated with an automobile detailer liquid. The superhydrophobic surface was a microscope glass slide coated with a rain repellant. Their task was to identify each surface by depositing water droplets on each slide and observing its behavior.

One student in each group was designated as the recorder and they were responsible for keeping track of every variable that was changed as the team explored each surface. Once they identified each surface they were given a list of guided questions so they could discuss among each other the structural differences of each coating. After the group discussion, each student had to sketch what he or she believed the structure of the hydrophobic coatings would look like under a microscope, and under an electron microscope using their content knowledge of physics, chemistry and biology. The drawings would ideally show a physical structure that could explain characteristics of hydrophobic or superhydrophobic effects.

At the end of the activity the properties of each surface were revealed to the students. The instructor also demonstrated how to measure the water droplet's contact angle, a common technique used in industry for determining the wettability of a surface. If there was extra time in class or the following class period, students were able to measure the contact angle with a smart phone camera application.

Results and Discussion

The lesson was implemented as an inquiry-based activity so students would have the opportunity to form their own experiments and make conclusions from the data they collected. This approach promotes active learning and has been shown to be more effective at increasing conceptual understanding [11]. Upon receiving the slides most groups were able to quickly distinguish between the hydrophilic and hydrophobic slides by observing the shape of the water droplet. The hydrophilic surface is wettable so the water drop spreads out over the microscope slide while the hydrophobic surface is non-wettable so the water drop beads into a spherical droplet.

Some of the observed behavior was in line with science and engineering practices as outlined in the NGSS [8]. The most prominent practice observed in groups was planning and carrying out investigations during the portion of the activity when students were conducting experiments to distinguish between the hydrophobic and superhydrophobic surface coatings. Students were observed adding multiple drops in one location to see if a larger water drop would flatten out. They also deposited drops in various regions of the glass slide to verify if the effect was repeatable everywhere on the surface. Furthermore, watching some of the droplets slide off the superhydrophobic surface enticed some groups to change the elevation angle of the two other surfaces to see if the same effect occurred. A couple of groups reported a "cloudy streak" left on the surface as water droplets slid off the glass and attempted to construct an explanation for that behavior.

Through repeated iterations of experiments most students were able to correctly distinguish between the three surfaces (Figure 1). Out of the 51 students who answered the identification questions, hydrophilic and hydrophobic surfaces were correctly identified 83.7% and 80% of the

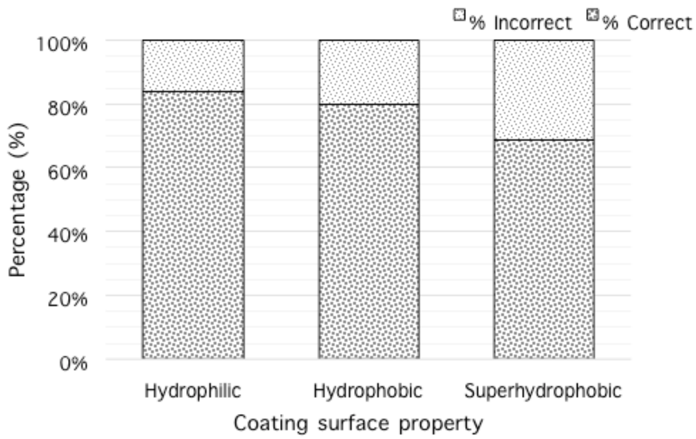

Figure 1: Percentage of students who identified the surface coatings by their correct properties (hydrophilic, hydrophobic, and superhydrophobic) compared to the percentage of students who identified them incorrectly.

time, respectively. This is most likely due to the transfer of content knowledge from other science classes or from understanding the meaning of the root words. Only 68.6% of the students identified the superhydrophobic surface correctly. To make this correct assertion one has to recognize that superhydrophobicity is a magnitude greater than hydrophobicity so if the other two surface coatings were identified incorrectly then the superhydrophobic surface coating would also be identified incorrectly.

Another science and engineering practice observed was constructing explanations to justify droplet behavior on the slides. These were apparent as groups discussed the guided questions. Some students believed the hydrophobic coating was composed of polar molecules thus preventing water drops from spreading on the surface. Others pointed to the rough surface as impeding the droplets from spreading evenly. A few students attributed the behavior on the superhydrophobic to having a lower surface tension leading the water to repel from the surface.

The practice of engaging in argument from evidence was also evident from the student's written descriptions of each coating. Their responses were coded into four categories: 1) water droplet displacement, 2) droplet/bead shape, 3) structure of the coating, and 4) other. The first category grouped responses dealing with the observed physical movement of the water droplet as it contacted the surface, for example "absorbs", "falls off", "speeds", "slides", "binds", etc. The second category grouped words depicting the water droplet shape, such as: "clumps", "disperses", "beads up" and "small surface area". The third category of structure included words signifying the coating's perceived structure. These included, "porous", "smooth", "rough", "bristles", "bumpy", etc. The final category, "Other", encompassed all other words not fitting into the aforementioned categories.

The distribution of coded terms was similar for the hydrophobic and superhydrophobic coatings (Figure 2). The displacement and structure categories differed by 2% and 1%, respectively, while bead shape category differed by 5.5%. This implies students identified the droplet shape as the main physical characteristic distinguishing a hydrophobic and a superhydrophobic surface. This is a good assertion as in many industrial processes the physical contact angle between a water droplet and the surface is quantified to distinguish the wettability of a surface. The descriptions

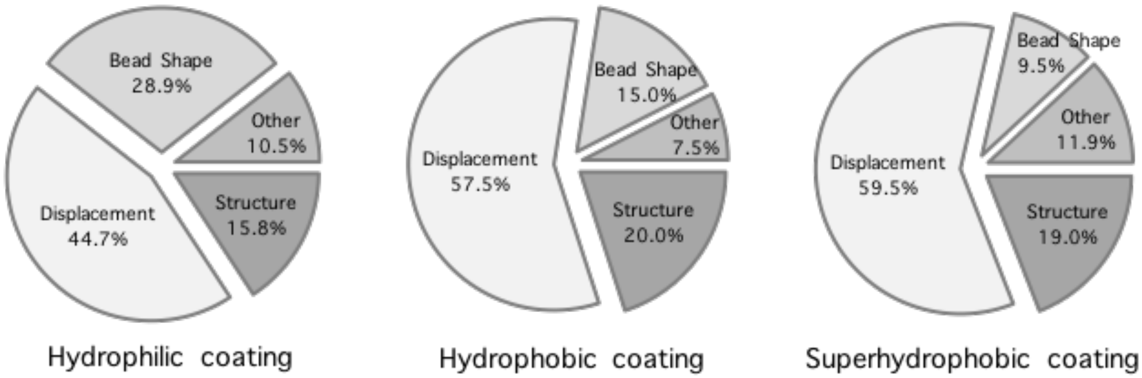

Figure 2: Charts summarize the observations students made as evidence to help support their reasoning in identifying each surface coating.

for the hydrophilic coating had a much lower frequency of words in the displacement category (44.7%) while the bead shape frequency (28.9%) was much higher than the hydrophobic coatings. This agrees with the behavior of the water droplet on the hydrophilic surface as it spreads out on the surface. The written descriptions shows that students are engaging in the practice of gathering evidence from their experimental observations to make their arguments.

A total of 79 sketches were analyzed for evidence depicting the composition of a hydrophobic coating as would be seen under an optical microscope and an electron microscope. The majority of features sketched of the hydrophobic surface under an optical microscope fell into three categories 1) water droplets, 2) structural features, and 3) molecular structures. If the drawings depicted more than one category then they were counted for each of the applicable categories. Most students drew a lateral perspective while a few drew an aerial view similar to what one would see through a microscope's eyepiece. The most frequently depicted concept was a magnified view of the water droplets on a microscope slide (Figures 3a and 3b). This is most likely because they have had an experience using a microscope in a biology class or other science classroom. Some of the drawings also depicted a rough surface, which most likely corresponds to the coating on top of the microscope slide (Figures 3c and 3d). There was a small percentage of sketches that depicted molecular structures of a water molecule or bonding (Figure 3b), which would not be observable under an optical microscope.

The sketches of the hydrophobic coatings as they would appear under a scanning electron microscope (SEM) depicted various themes. A large part of the sketches depicted a magnified view, approximately 10x to 100x of their optical microscope drawings. For example, Figure 3a corresponds with Figure 4a and it appears a water molecule is magnified in the latter. Figure 3c corresponds with Figure 4c and here it appears an array of pillars or divots has been enlarged.

Another occurrence was the depiction of atomic structures, molecular bonds and organized chemical structures (Figure 4b and 4d). These structures are typical of the Angstrom scale or approximately 10 to 100 times smaller than the best resolution of a formidable SEM. Although students were not expected to have previous experiences using an electron microscope, it was explained an SEM could take micrographs at a significantly smaller scale than a microscope. It is important to make this distinction clear because understanding the capability of this tool in visualizing the nanoscale could help students bridge the gap across length scales. Schank et al also reported students having difficulty explaining why electron microscopes and other devices could “see” features at the nanoscale [6]. It is plausible students have the misconception of a scanning electron microscope, due to its name, being able to “see” features on the length scale of an electron, as opposed to its function of utilizing scattered electrons to form surface topographies.

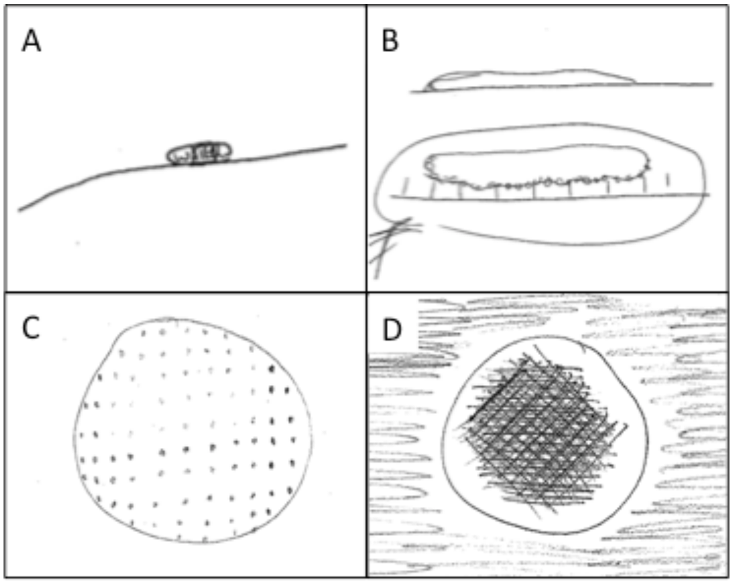

Figure 3: Representative student sketches describing what the composition of a hydrophobic surface would look like under an optical microscope.

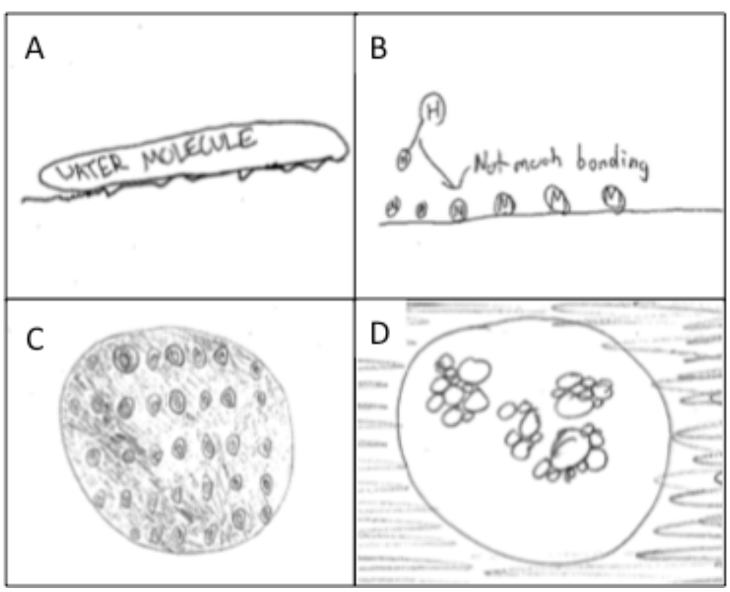

Figure 4: Representative student sketches describing what the composition of a hydrophobic surface would look like under a scanning electron microscope.

Sketches were also evaluated by the type of structures depicted and then categorized into two of the groups described by the science-content big ideas of NSE: Structure of Matter and Forces & Interactions. The structure of matter category was further divided into two other categories: hierarchy of structures and molecular bonding. The forces and interactions category was subdivided into forces, electrical charges, and polarity.

The most frequent type of feature sketched was related to organization (Figure 3). This means that out of all the features analyzed in the individual drawings 58% of those related to organized structures. Some were clearly composed from the building blocks of single atoms while others looked like pillars, lipid bilayers or rough/bumpy surfaces. Students seemed to be able to depict hierarchies of scale even though they did not describe it in their written reflections. Only 23% of depictions were related to a physical force that might occur due to repulsion, attraction or a difference in charges. The categories represented least in student sketches demonstrated basic structures of chemical bonding (10%), charges (5%) and polarity of a molecule (4%).

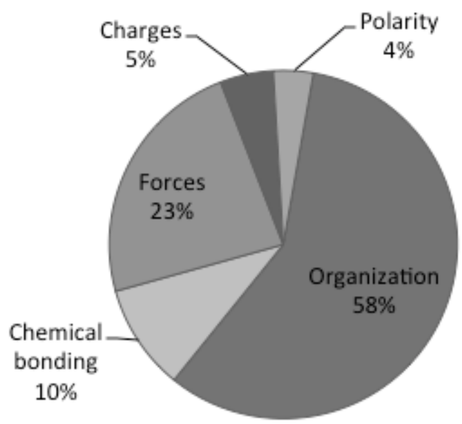

Figure 5: The chart gives a representation of the content areas clearly depicted in the student sketches after being asked to draw the hydrophobic surfaces under a microscope.

Conclusion

With the relative parity between NGSS and the big ideas of NSE, and the interest of integrative STEM, the climate is ideal to incorporate nanoscale science activities in K-12 classrooms. Nanoscale science lessons can cover content spanning the science disciplines so they are particularly well suited to synthesize concepts across the different fields. It also has the potential to captivate students because the foundational science content they learn directly relates to modern technologies. An even greater benefit is the opportunity for teachers to guide students through NGSS science and engineering practices, especially when presented as an inquiry-based activity. Although, not all the practices were observed it was clear that students effectively collected observations from their experiments, discussed their results among their teams, and formed arguments to correctly identify the hydrophobic and hydrophilic surfaces, 80% of the time.

The sketches produced to describe hydrophobic surfaces revealed some mixed results. On the one hand a majority of students were able to depict a magnified view of a water droplet on a coated surface as would be seen through a microscope. They also depicted organized structural features that would signify a rough surface at the macroscale. Many sketches were of features that would only be seen at the atomic scale: atoms forming larger molecules through bonding, charges causing organized structures to repel. However, it was difficult to extract how students visualized the intermediate scales, i.e. nano and microscales. Although students were not expected to understand the operation of scanning electron microscopes they should recognize the existence of orders of magnitude between the atomic scale and what is visible under a microscope. The lack of clarity could be in part due to K-12 science instructional units shifting between length scales. In chemistry a large part of content is focused at the atomic level but then transitions to experiments at the macroscale. Physics deals with atomic scale forces and charges, macro scale mechanics and large planetary motion. Perhaps, biology does the best at bridging content across small scales as cellular organelles are in the nanoscale, cells and blood are in the microscale and animal anatomy is discussed at the human scale. In both physics and chemistry there seems to be a large gap in teaching along the nanoscale and microscale so it is difficult for students to span the gap on their own. This is usually clarified at the undergraduate and graduate levels but the NSE lessons present an early way to directly engage in content addressing size and scale.

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