

## **Student understanding of “surface-area-to-volume ratio” and its relationship to property change in the nano-science engineering context**

Greg Light, Su Swarat, Eun-Jung Park, Denise Drane  
Northwestern University

Paper presented at the Research on Engineering Education Symposium (REES), Davos, Switzerland, January, 2008

### **Extended Abstract**

Since Feynman (1960) invited us to the “room at the bottom,” nanoscience and technology has not only attracted considerable interest from scientists and engineers but also from the general public. While it has grown as a new, potentially rich field in science, substantial attention has yet to be given on research about its educational perspectives. Recent studies (Stevens, et al. 2006, Wansom et. al. in press) with scientists, engineers and learning scientists have identified the concept, “surface-area-to-volume ratio” (SA/V) as one of the ‘big ideas’ or key concepts central to the understanding of nanoscale science and technology. Indeed, SA/V is a prerequisite to understanding size-dependent properties and behaviors and change that are at the core of nanoscience. Previous studies have found that students tend to have difficulty truly understanding SA/V beyond its mathematical equation (Cohen et al., 1999), and that teachers often refer to SA/V without access to students’ actual understanding of the concept (Gilbert, 1982). This study explores students’ understanding of “surface-area-to-volume ratio” in the nano-science engineering context, focusing specifically on how they understand SA/V in relation to property change. Informed by Variation Theory (Marton & Booth 1997, Marton et al., 2004), this study focused on differences in the ways in which students understand a particular concept or phenomena, with particular attention paid to the aspects of variation that distinguish these different understandings.

### **Methods**

#### *Data Collection*

Data for this study were collected from 30 undergraduate engineering majors enrolled in an introductory level engineering design course with a focus on nanoscience concepts. A survey including 5 SA/V items requiring multiple-choice and short-answer responses were administered at the beginning (pre-survey) and the end (post-survey) of the course. Fifty-nine complete responses to the survey (30 pre and 29 post) were obtained from the students. In addition, eight students randomly selected from the sample participated in a follow-up “think-aloud” interview. Each interview was conducted by two researchers, and was audio- and video-recorded.

### *Survey Analysis*

Students' pre- & post-survey responses were reviewed, and a grading rubric was established using an inductive approach to capture all possible variations in the responses. The multiple-choice part and the written justification part for each question were reviewed holistically in the process of developing the grading rubric. In general, the score distribution (Table 1) distinguished between correct and incorrect answers plus explanations which revealed varying understandings of SA/V in the nano-context. Each question was graded on a 0-5 scale, with 0 being the lowest score indicating wrong choice and no explanation, and 5 being the highest score indicating correct choice and a sophisticated explanation.

Table 1. Overview of the survey grading rubric

|                           |  |
|---------------------------|--|
| <i>Scores 4 and above</i> | Correct choice + Explanation demonstrated a sound understanding of SA/V and its relationship to property change                        |
| <i>Score of 3</i>         | Correct choice + Explanation limited to SA only and its relationship to property change  |
| <i>Score 2 and below</i>  | - Correct choice + Explanation not related to SA/V or SA; Or<br>- Correct choice + No meaningful explanation; Or<br>- Incorrect choice |

Two researchers graded approximately 20% of the responses (including both pre and post) using the rubric. The inter-rater reliability, Kappa = 72.8%, indicated a satisfactory degree of agreement.

### *Interview Analysis*

Interviews were transcribed, and the transcripts were reviewed to identify major themes or areas yielded by the responses. Codes were then developed inductively to capture the variations within each theme/area. Each interview transcript was coded, and the coding results were evaluated holistically with an attempt to capture the overall patterns of students' understanding of SA/V.

## **Preliminary Results**

### *Survey results*

Paired t-test conducted on the grading results of each question showed no significant pre vs. post differences ( $p > 0.05$ ). Thus, in order to demonstrate the full range of variations, pre- and post-responses were combined ( $n=59$ ) and treated as independent responses (i.e. no pre- vs. post-response comparisons was conducted). The distribution of the students scores (Figure 1) showed variation in the students understanding of SA/V across the three levels of

understanding of SA/V: **Level I** – Students who understand SA/V with respect to the relationship of *both* surface area and volume and property change (scores above 4); **Level II** – Students who understand SA/V with respect to the relationship of *only* surface area (i.e. no volume) and property (scores of 3); **Level III** – Students who do not appear to understand or incorrectly understand the relationship of SA/V to property change (scores below 2). It is interesting that only Level I understanding appeared to recognize the *ratio* in SA/V as relevant to size dependent properties. For a substantial portion of the students (Level II), the relationship of SA/V to property change is essentially understood entirely in terms of the increase in surface area alone.

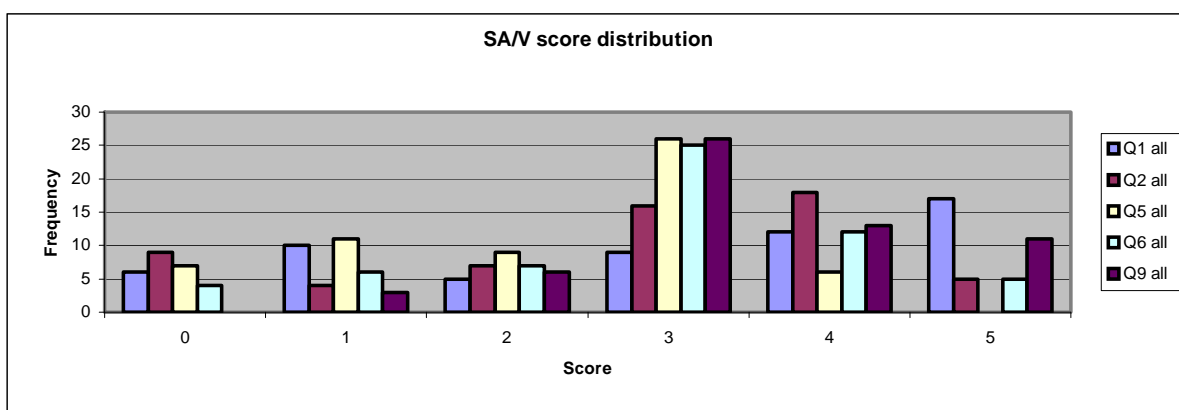


Figure 1. Student survey score distribution by question

### Interview results

The three general levels of understanding discussed above were also identified in the interview data. Surprisingly, only one student was able to explicitly demonstrate a solid Level I understanding of SA/V – that is, his explanation of the concept with respect to size-dependent properties involved both the surface area and the volume part. Most of the students seemed to have a Level II understanding, describing the concept SA/V only in terms of its surface area – that is, they seemed to view the relationship between SA/V ratio and property change only in terms of surface area change, and ignored the role of volume. Two students, moreover, demonstrated a somewhat unstable understanding of SA/V – their explanations switched between a Level II discussion of SA only, and a Level III response of not even mentioning surface area or volume at all.

In addition, only the student with Level I understanding appeared to be able to explain why SA/V ratio change leads to property change in terms of the different characteristics of surface molecules or atoms (e.g. less bonding with neighboring molecules/atoms, thus requiring less energy to “break free”). Student exhibiting Level II understanding, on the other hand, focused their explanations exclusively on the idea of *exposure* – either more surface area is exposed, or more molecules/atoms are exposed at the surface. Moreover, Level II students’ understanding of the connection between SA/V ratio

and property change appears to be contextually limited, specifically to properties such as reactivity and solubility. That is, when asked about why these properties change as size changes, students were able to provide a coherent explanation related to SA/V (mostly in terms of SA change only) in terms of more surface area or more molecule/atom exposure. However, when asked about other properties that are dependent on SA/V such as melting point, students were not able to make the link between SA/V and the property change.

## **Discussion**

Our preliminary analysis suggests that variation in student understanding of SA/V in the nanoscience context appears to be due to a limited understanding of the mechanism between SA/V ratio and property change – that is, their understanding is dependent on the particular nature of the property change. If students understand the mechanism primarily as more surface area and/or molecule/atom exposure (Level II), they would have an easy time understanding that cutting something into smaller pieces leads to more exposure, and thus higher reactivity or solubility. However, understanding melting point change requires not only understanding that more molecules/atoms are at the surface, but also that these surface molecules/atoms behave differently than their bulk counterparts. Therefore, if students' understanding does not go beyond the idea of “exposure,” they are less likely to understanding the connection between SA/V ratio and melting point (or other similar properties) change.

While our data do not provide any information regarding the source of students' conception, we speculate that the prevalence of Level II understanding could be due to prior instruction. Because the idea of SA/V ratio change can be easily visualized through examples of cutting something into smaller pieces, and students often have had the real life experience of dissolving things of different sizes, instruction on SA/V ratio often involves examples of reactivity or solubility, and does not expand to other examples. This may cause students to associate SA/V ratio change with limited property contexts only.

Lastly, the limited data we collected also pointed out that students are likely to have an unclear understanding regarding the size or scale range in which the connection between SA/V ratio and property change can be observed. Some believe such connection is continuous throughout all size continuums, others think it is applicable to limited range only (e.g. nano-scale only). We also witnessed the belief that the observation of such connection is only possible when there is dramatic size differences (i.e. the size difference needs to meet some sort of a “threshold” value in order for property change to be observed).

## **Future Plans**

This study is part of an on-going study of undergraduate student understanding of the “Big Ideas” in Nano-scale science and engineering funded by the National Science

Foundation through the National Center for Learning and Teaching: Nanoscale Science and Engineering (<http://www.nclt.us/>). This study is a preliminary study of SA/V which will link to ongoing studies of the student understanding of both Size and Scale (Light et. al. 2007) and the particulate nature of matter (Park & Light 2007). Future plans of this specific research include further studies including participants from a wider undergraduate population, exploring the nature of the variations in student understanding of SA/V and its relationship to different categories of size-dependent properties, examining the connections of these understandings to understandings of size and scale and understandings of the particulate nature of matter. Ultimately, it is our hope to identify and develop both instructional materials and pedagogical practices that will help foster more sophisticated student understanding of “surface-area-to-volume ratio,” and to create assessment items that will help reveal student understanding of this phenomena.

### **Acknowledgement**

The authors would like to acknowledge the National Science Foundation and the National Center for Learning and Teaching: Nanoscale Science and Engineering for support for the research reported here: Grant No.: ESI-0426328/002.

### **References**

- Cohen, A., & Moreh A. (1999). Hands-on method for teaching the concept of the ratio between surface area and volume, *American Biology Teacher* 61 (9) (Nov/Dec 1999)
- Feynman, R. P. (1992). There's plenty of room at the bottom. *Journal of Microelectromechanical Systems*, 1(1), 60-66.
- Gilbert, S. (1982). Surface, volume and elephant's ears. *The Science Teacher*, 49, 14-20.
- Light, G., Swarat, S., Park, E. J., Drane, D., Tevaarwerk, E., & Mason, T. (2007). Understanding undergraduate students' conceptions of a core nanoscience concept: size and scale, In *the Proceedings of the International Conference on Research in Engineering Education*, June 23-24, 2007, Honolulu, Hawaii.
- Stevens, S., Sutherland, L., Schank, P., & Krajcik, J. (2006). The big ideas of nanoscience. [http://www.nclt.us/news/news\\_docs/Big\\_Ideas\\_of\\_Nanoscience-draft2.pdf](http://www.nclt.us/news/news_docs/Big_Ideas_of_Nanoscience-draft2.pdf).
- Marton, F., & Booth, S. (1997). *Learning and awareness*. Mahwah, New Jersey, Lawrence Erlbaum Associates.
- Park, E. J., & Light, G. (In Press). Identifying atomic structure as a threshold concept: student mental models and troublesomeness, *International Journal of Science Education*.
- Wansom, S., Mason, T., Hersam, M., Drane, D., Light, G., Cormia, R., Stevens, S., and Bodner, G., (In Press) A Rubric for Post-Secondary Degree Programs in Nanoscience and Nanotechnology, *International Journal of Engineering Education*.

Light, G., Swarat, S., Park, E.J., & Drane, D. (2008, January). *Student understanding of surface-area-to-volume ratio and its relationship to property change in the nanoscience engineering context*. Paper presented at the Research on Engineering Education Symposium (REES), Davos, Switzerland.

Light, G., Swarat, S., Park, E.J., & Drane, D. (2008, January). *Student understanding of surface-area-to-volume ratio and its relationship to property change in the nanoscience engineering context*. Paper presented at the Research on Engineering Education Symposium (REES), Davos, Switzerland.