Exploration of Student Understanding and Motivation in Nanoscience

Abstract
We investigated 7-12th grade students' interest and motivation in nanoscience concepts and phenomena. Certain types of topics may be used motivate students to learn nanoscience concepts, therefore how students' interests vary among school context (urban, suburban, rural), grade level, and gender were investigated. A survey of 416 students in urban, suburban and rural communities measured interest in the nanoscience-related topics and phenomena. We found that a majority of students expressed at least some interest in many nanoscience-related topics and phenomena as they were presented. However, interest levels differed according to school context, grade level, and gender. From student interviews, we identified categories that govern student interest including: personal interests, how it relates to the student's everyday life, prior knowledge, prior experience, hands-on activities, and/or use of chemicals. While hands-on activities were a strong factor in student generating interest, this alone was not enough to sustain it; other factors also play a significant role in student interest and motivation. These results can contribute to the efforts of curriculum developers and instructors to create engaging and motivating experiences for students, which could in turn lead to increased student learning and understanding in nanoscience and science in general.

Rationale, Research Problem, and Research Questions
Student motivation, interest, and engagement are important aspects for student learning in science education. Positive student attitudes toward science have been correlated to higher performance on science assessments for the majority of students (Neathery, 1997). Eccles and Wigfield (2002) have shown that "interest is more strongly related to indicators of deep-level learning than to surface-level learning" (p. 7) which may explain why students with low interest levels in science perform poorly on exams. As students progress through school, their interest in science appears to decline (Neathery, 1997). A parallel trend has been observed with students' performance on science standardized exams as they progress through school (Greenfield, 1997; Haussler & Hoffmann, 2002). This suggests that the lower performance of older students on these exams is due at least partially to a lack of interest in science.

Several promising strategies have been developed by science educators in the effort to increase students' interests and positive attitudes toward science. Schwartz-Bloom and Halpin (2003) investigated the introduction of pharmacology topics into biology and chemistry curriculums and found that this topic was of interest to students in both science realms and thus caused an increase in student learning. Their research builds on previous research which found that when information was submerged within meaningful contexts and applications, learning was promoted (Brooks & Brooks, 1993). Teaching strategies have also been shown to affect students' interests and learning (Von Secker & Lissitz, 1999). One such practice is the use of hands-on activities as shown by Stohr-Hunt, who found that students "who engaged in hands-on activities every day or once a week scored significantly higher on a standardized test of science achievement than students who engaged in hands-on activities once a month, less than once a month or never" (1996, p. 101).

Nanoscience and nanotechnology are emerging scientific fields that contain concepts and phenomena that are not usually addressed significantly in traditional science curricula, but in which students might be interested. In this paper, we investigated 7-12 grade students' engagement and motivation in nanoscience concepts and phenomena. In particular, we investigate whether we can identify activities based on nanoscale phenomena that will motivate diverse learners to explore and learn nanoscience topics. Based on previous research, we do know that student achievement increases significantly when the science subject matter is relevant to the students' own lives (Schwartz-Bloom & Halpin, 2003). However, we do not have a clear understanding of what these topics that are interesting and relevant to them are, or how general this relevance might be across the student population of the nation. Moreover, little research has been conducted to investigate what aspects of a topic most influence students' interests and motivation. To this end, we investigated what types of topics can be used motivate students to learn nanoscience concepts. In order to make claims about the general population, we are investigating how these interests vary among school context (e.g., urban, suburban, and rural), grade level (e.g., high- and middle-school), gender, ethnicity and academic ability. In addition, we report on students' suggestions for improving interest, and excitement in science class as related to nanoscience concepts.

Methods

Participants

The population consisted of Midwestern students from middle and high schools from a diverse, urban community where approximately 50% are considered to be economically disadvantaged (N=156), and predominantly white middle-class suburban (N=96) and rural (N=164) communities. From this population, students were selected for interviews based on their gender and academic ability levels in science (N=17, 11, 12 per school community).

Instruments

<u>Hands-On Activities</u>

We developed four hands-on activities that demonstrate nanoscience phenomena:

1. Waterproof Material
   - Demonstrated how nanotechnology directly affects our daily lives.
2. The Hopping Magnet
   - Modeled a scanning probe microscope, a critical instrument in the advancement of nanotechnology (Lorenz et al., 1997).
3. Changing the Color of Gold
   - Illustrated how properties of matter at the nanoscale differ from those at the macroscale (McFarland et al., 2004).
4. Easy-Stir
   - Illustrated the power of electric forces on macroscopic properties (Johnson, n.d.).

<u>Survey</u>

We developed two 3 point Likert-type surveys to evaluate sets of nanoscience hands-on activities and interest questions. The surveys asked students to provide their level of interest in these items (very interested, kind of interested, or not interested). The nanoscience hands-on activity survey was developed to measure students' interest in four nanoscience phenomena. Students were then asked to rank the four activities from most to least interesting. The interest survey contained 11 questions designed to measure students' interest in learning about nanoscience and nanotechnology topics as compared to their normal science class:

1. How do we know atoms exist (Atoms)?
   - We are now able to "see" atoms with scanning probe microscope.
2. If a penny is made of tiny particles (atoms) why doesn't it fall apart (Penny)?
   - Solids are held together by strong attractive electrostatic forces.
3. What do a pencil, diamond ring, car tire, and charcoal have in common (Pencil)?
   - All are made of the same element in different arrangements.
4. How can a gecko walk upside-down on the ceiling (Gecko)?
   - Van der Waals forces are amplified due to extensive surface area.
5. When will gold no longer be the color gold (Gold)?
   - Properties of matter on the nanoscale differ from those on the macroscale.
6. How did aspirin stop my headache today and my fever last week (Aspirin)?
   - Biomolecular recognition and specificity is dependent on nanoscale forces (electrostatic, hydrogen bonding and van der Waals interactions)
7. What kinds of machines are small enough to fit inside a living cell (Machines)?
   - Molecular machines are nanoscale machines created by Nature.
   - Man-made machines have nanotechnology applications.
8. What can be done to keep a window clean, making sure water and dirt do not stick (Window)?
   - Nanoparticles coat the window preventing water and dirt from coating the window.
9. How can we make DNA act like a robot (Robot)?
   - DNA can be used to support nanoscale self-assembly. Self-assembly is a critical procedure for building things that are too small to build with man-made machines.
10. What do Styrofoam, fog, milk, jell-o, latex paint, and steel have in common (Common)?
    - All are colloids—suspensions of nanoscale particles.
11. Why does a CD have so many colors on the back? Do those colors have anything to do with the music stored on it (CD)?
    - Illustrates the impact of nanotechnology on information storage and our daily lives.

<u>Interview Protocol</u>

We developed an interview protocol to investigate why students were or were not interested in the items on the hands-on activity and interest surveys. The interview probed students about their interest level for each item, and asked students whether they could explain how the activities worked or answer the driving questions. The interviews lasted between 20-25 minutes.

Data Analysis

Surveys were analyzed to give the means for each for each activity and interest question with 1 corresponding to "not interested" and 3 to "very interested." The Bonferroni test and t-test parametric tests were used to test for significance between the student populations at the 95% confidence interval. In order to evaluate why students expressed a given level of interest, the interviews were analyzed qualitatively. Through a phenomenographical analysis (Marton, 1994), we identified several categories that govern student interest. Categories were created based on common themes seen in the transcripts for questions that pertained to student interests in the activities performed and the questions about nanoscience phenomena from the survey.

Results

Preliminary survey results

To understand how students responded on the surveys, descriptive analysis of each survey were conducted (see Table 1).

Table 1. Descriptive results of means for hands-on activity and interest surveys

	Means (1=not interested; 3=very interested)					
Hands-On Activity	Suburban High (N=41)	Suburban Middle (N=55)	Rural High (N=90)	Rural Middle (N=74)	Urban High (N=63)	Urban Middle (N=13)
1. Waterproof [2,3]	2.15	2.49	1.97	2.32	2.49	2.15
2. Hopping Magnet [2]	2.20	1.82	1.87	2.16	2.39	2.31
3. Changing Color [1,3]	1.90	2.15	1.93	2.43	2.17	2.15
4. Easy-Stir [1]	2.20	2.09	2.07	2.35	2.41	2.08
Interest Question	Suburban High (N=41)	Suburban Middle (N=55)	Rural High (N=88)	Rural Middle (N=74)	Urban High (N=137)	Urban Middle (N=19)
1. Atoms [1]	1.85	1.76	1.69	1.88	1.76	1.84
2. Penny [2,3]	1.95	2.18	1.98	2.34	1.87	2.11
3. Pencil [1,2,3]	2.24	2.27	2.09	2.50	2.03	2.00
4. Gecko [2,3]	2.71	2.65	2.53	2.64	2.27	2.16
5. Gold [3]	2.10	2.18	1.92	2.38	2.25	2.32
6. Aspirin [1]	2.56	2.40	2.23	2.47	2.28	2.05
7. Machines [1,3]	2.41	2.49	2.22	2.58	2.21	2.47
8. Window	2.32	2.02	1.92	1.96	1.90	2.21
9. Robot [1]	2.41	2.35	2.18	2.47	2.32	2.32
10. Common [3]	2.17	2.11	2.06	2.28	1.97	2.05
11. CD [1,2,3]	2.68	2.71	2.44	2.82	2.46	2.58

[1.] Gender Difference [2.] School context (district) [3.] Grade difference

In examining the hands-on activities, no trends can be found as to the most interesting and least interesting activities, as these varied across all populations. Each activity was selected as the most interesting activity by at least one school population. The only activity not ranked as the least interesting was the Waterproof material activity.

Gender differences at the 95% confidence interval were seen among the Changing Color ($p=0.014$) and Easy-Stir ($p=0.003$) experiments in which females were more interested than males. These two activities were considered to be more hands-on in nature than the previous two experiments that were performed by the students. Significant differences were between the urban, suburban, and rural school districts in the Waterproof and Hopping Magnet experiments.

In the Waterproof activity, differences were seen between the rural and suburban districts ($p=0.032$) and the rural and urban districts ($p=0.003$), in which the suburban and urban populations were more interested than the rural population. The Hopping Magnet showed differences between the urban and rural districts ($p=0.001$) and the urban and suburban districts ($p=0.001$), where the urban district was more interested. Waterproof (p=o.007) and Changing Color ($p=0.000$) were significantly different between middle- and high-school grades. As is expected from previous research, the middle-school population was more interested than the middle-school population. Although not significantly different, the high-school population was more interested than the middle-school population in the Hopping Magnet.

Examining the driving questions, the CD question, discussing the different colors on the back was of greatest interest to students all school populations, except for the suburban and rural high-school populations. These populations instead indicated that the Gecko question was of greatest interest to them, followed by the CD question. A significant difference was found between the suburban and urban districts ($p=0.026$) for the CD question, in which the suburban district was more interested than the urban district. This was found despite the fact that the CD question was the most interesting question for both the urban middle- and high-school populations. In the suburban and rural middle-school populations, the Gecko question was ranked as second, however, this question was ranked fourth in the urban high-school and did not even rank in the top five questions for the urban middle-school. Significant differences were found between the rural and urban districts ($p=0.000$) and the suburban and urban districts ($p=0.000$), in which the rural and suburban districts were more interested.

The Aspirin, Machines, and Robot questions ranked in the top five questions for the rural and suburban populations as determined by mean scores. The Pencil question also ranked as a top five question for the rural middle-school students, as the mean score for both the Aspirin and Robot were the same. The difference in means for the Pencil question was significant between the rural and urban districts ($p=0.009$) and the suburban and urban districts ($p=0.049$), where the rural and suburban students were more interested. The urban high-school students selected CD, Robot, Aspirin, Gecko, and Gold in their top five. This differs from the suburban and rural populations in that the urban high-school students were more interested in the Gold question compared to the Machines question. The urban middle-school population ranked CD, Machines, Gold, Robot, and Window in their top five. This was the only population which selected Window and did not select either Gecko or Aspirin in their top five questions. One question found to have a significant difference, but not ranked in any populations top five, was the Penny, in which there was a difference in the rural and urban districts ($p=0.006$), with the rural district more interested than the urban district.

When examining gender, there were differences in the Atoms, Pencil, Aspirin, Machines, Robot, and CD. Females were more interested in Pencil ($p=0.038$), Aspirin ($p=0.049$), and CD ($p=0.020$). Males were more interested in Atoms ($p=0.004$), Machines ($p=0.000$), and Robot ($p=0.001$). Some of these differences may be contributed to classic stereotypes where females are more interested in jewelry (diamonds in Pencil question) and health fields (Aspirin), where males are more interested in mechanics (Machines and Robot).

As previous research has shown, middle-school students are more interested in science than high- school students. This trend was again shown in the driving questions, in which the middle-school population was more interested in all driving questions compared to the high-school population. Middle-school students were much more interested in Penny ($p=0.000$), Pencil ($p=0.001$), Gecko ($p=0.028$), Gold ($p=0.016$), Machines ($p=0.000$), Common ($p=0.039$), and CD ($p=0.000$).

The Atoms question had the lowest mean in all populations indicating that students were least interested in discovering the answer to this question. Overall, when students were asked to select their most favorite and least favorite driving question, students selected the Gecko (23.5%) and the CD (25.5%) as their most favorite question. The least favorite question was the Atoms (30.4%).

Preliminary interview results

The categories that were developed included (a) students' personal interests, (b) relationship of activities to everyday life, (c) prior knowledge, (d) prior experience, (e) hands-on nature/experimentation, and (f) use of chemicals. The table below (Table 2) provides descriptions and exemplars for each category. If categories contained both positive and negative comments, examples of both were given. Throughout the coding process, it was found that some student comments could exist in more than one category, and were therefore coded in all possible categories. The categories listed in Table 2, are listed in order of most common to least common category.

Table 2. Descriptions and exemplars for motivation category

Category	Description	Example Statement(s)
Personal interests	Items are related to students' current interests (science and non-science)	• [Kind-of interested in the Easy-Stir because] "I'm an artist and I know it had to do with paint and stuff, so…something that I do outside of Chemistry class, kinda like the magnets." • [Not interested in Gecko because] "I like doing like forensic science and stuff like that—like when it comes to like plants and living animals and stuff, I'm not too interested."
Relation to everyday life	Items relate to general population or everyday life	• "I'd like to explore that a little more just because it happens, or it deals with everything around us." • "The more they relate to our everyday lives, the more we're gonna be willing to pay attention and learn about them cause we can interact with it more than just going to class, sitting in class, and doing the homework, like we can put it to our lives."
Prior knowledge	Student already learned	• "I think it's just because since I've sat in

	or not learned about the topic in science class	Chemistry class and we've talked about atoms and atoms and atoms, just after talking about them for so long, and then doing labs and discoveries with them, not too fond of them." • [Regarding the Waterproof material] "I've actually never seen or heard about stuff that could do that and I just thought it was kind of cool."
Prior experience	Student had personal experience with it, but may not be able to explain it	• "All I saw was a color change and there's a lot of different experiments that, you know, have a different color change" • "I just thought it was kind of cool because I'd never actually tried it or noticed that it would do that."
Hands-on/ experimentation	Student recognizes the active process of discovery (or mentions the terms "hands-on" or "experiment(ation)"	• "I like to do like hands-on activities were I can mix up things and see what would happen if I put that with that and that." • "I like hands-on stuff, so maybe if we did a little more like got deeper into the subjects and you know tested out what the different components or whatever, that might be fun."
Use of chemicals	Student used the term chemical in explanation	• [No interest in the gold experiment because] "that has a lot to do with like chemicals" • "I'm interested in all the ones that we had to mix different chemicals together because I like to see what happens in the end. And the other ones I was not very interested in because I didn't get to use different chemical stuff."

Students' Personal Interests

The category labeled *Personal Interests* contained statements that related to students' personal likes and dislikes of topics. In this category, students related the topic directly to their likes and dislikes, rather than generalizing to life, which separated it from *Relation to Everyday Life*. Statements categorized here were considered unique to the student, rather than something that all students would have in common. Statements of general curiosity on behalf of the students were also categorized as personal interests. This category was the most prevalent among students, indicating that students' personal interests are one of the biggest influences into their interests in the nanoscience activities and phenomena. When activities or interest questions reflected onto students' personal interests, their interest was positively affected, while if students did not have a personal interest in the activity or question, they were not interested in learning how the activity worked or the answer to the question. Students' personal interests varied, for example there were students that both liked animals and did not like animals, which contributed to their interest or lack of interest in the Gecko question. This trend was also seen in examining the magnet activity.

Relation to Everyday Life

In the category *Relation to Everyday Life* students indicated that the activity or question related to everyday life, but was not specifically unique to their life. This category was differentiated from *Personal Interests* in that it was more general and not specific to the student. Students indicated that if the activities or interest questions about nanoscience related to everyday life or was something they could interact with daily, then they would be more interested in learning about the topic. Students also indicated that they would be more interested in science class if the topics related more to everyday life. Many times in their science classes students indicated that they were unable to see any relationship to what they were learning and how it affected their lives. Although students have various experiences, there are some common everyday life experiences to which science classroom activities could relate. Two questions to which several students responded positively were the Aspirin and CD. Reasons students enjoyed theses topics were because they had interacted with them and were able to relate them to their daily lives.

Prior Knowledge

Prior Knowledge is another category that was created. This category had comments indicating that students had already learned about the topic or had heard about the topic. Even if students were unable to describe how the experiment worked or the answer to the question, but believed they had already learned about the topic, their comment was coded as *Prior Knowledge*. Students who discussed doing similar experiments in the classroom were placed in the category *Prior Experience*. Students' interests in a topic were inversely related to their believed amount of prior knowledge. All of the statements in this category indicated that if students believed they had already learned the topic, they did not want to revisit the topic. However, even if students believed they had learned about the topic, they were not always able to give an accurate answer to the question. Those students with only a small amount of knowledge about a subject were interested in learning more about the topic. In general, middle-school students were more apt to be interested in the activities and interest questions. This category may partially explain why middle-school students are more interested as they have less prior knowledge about the questions asked.

Prior Experience

The *Prior Experience* category included comments that indicated that the student had interacted with the phenomena before. This category showed that students who had performed a certain activity many times were not interested, while those that have had a limited amount of experience had an increased interest in the topic. As they had interacted with the phenomena or topic of the driving question only a small amount of time, they wanted to find out more about it. Those students who believed they already had a great deal of experience, and therefore knew about the phenomena or topic of the driving question, were not interested because they had already done many similar experiments recently in class and believed they understood the principle fully. The explanations given by the students, however, were not always the correct scientific explanation for how the phenomena or driving question occurred. One experiment commented on by a high-school student that he did not enjoy was changing the color of gold. He said it was just "another color change experiment," which is what they saw in titration experiments. Middle-school students did enjoy this experiment, as they have not interacted with as many color change experiments.

Hands-on/Experimentation

Student responses were placed in the *Hands-on/Experimentation* category if they mentioned terms hands-on or experiment. Some students discussed the use of hands-on/experimentation as why they were interested in the activity or interest question, however, this category was mentioned much more in response to how to increase interest in science class and in some of the driving questions. Many students discussed that they enjoy hands-on experiments and like testing and exploring to see what will happen. This category was composed of all positive responses, indicating that if students are engaged in hands-on activities or experiments, they are more interested in learning about that topic.

Use of Chemicals

The category *Use of Chemicals* included students' statements that specifically indicated the term chemical(s) in response to why they selected their level of interest for the activity or driving question. In this category, no clear trend was determined. Some students enjoyed mixing chemicals together, while others were not interested in it. Although, using chemicals is considered to be hands-on which was found to positively affect students' interests, the use of chemicals in general did not indicate whether students would be more or less interested in the activity or driving question.

Conclusions

For the majority of students, higher performance on science assessments has been correlated to students' positive attitudes toward science (Neathery, 1997). We investigated what types of topics can be used motivate students to learn nanoscience concepts. There are several key findings from the results of this study. First, as indicated by the survey, students were most interested in learning about the CD and Gecko questions and least interested in learning about the Atoms question. The students' interests in the topics and nanoscale phenomena, however, were different depending on gender, school context, and grade.

Second, students were more interested in nanoscience activities and questions in which they saw a relationship to their personal interests or to everyday life. Students indicated that they were more interested in the activities, questions and science in general if the topics related to their everyday lives. This relationship to everyday life may explain why most students were very interested in learning about the CD, as a CD is an object that students can relate to and also enjoy interacting with.

Third, students tended to be interested in nanoscience questions and activities that were novel or could be experienced in a hands-on way, rather than questions that were more abstract. The gecko can be considered a novel animal to these students, as some students indicated that they had seen geckos on television, but had not interacted with the animal. This novelty may explain the great interest of the students. This conclusion may also partially explain why all populations were least interested in learning about atoms, as atoms are very abstract to students. They cannot interact with atoms, nor see them with their eyes. Students also commented that they would be more interested in science classes if there were more experiments.

Lastly, although students indicated that experimentation would increase their interest, just doing experiments is not enough to provide interest. Instead, we need to take into account the amount of prior knowledge and prior experience students have with a topic. Students were more apt to be interested when they had little or no prior knowledge and experience. This trend may also explain why the CD and Gecko questions were of great interest, while the Atoms question was of little interest. Students claim they have little prior knowledge of how CDs work and little prior knowledge or experience with Geckos, whereas, they claim to have learned about atoms repeatedly. Although, students claim to have learned about atoms, among other topics, they were not always able to give an accurate answer to the question.

Overall, our results suggest that there are certain nanoscience topics that interest 7-12 grade students, such as those that are novel, relate to everyday life, and provide room for experimentation. Nanoscience topics are also not currently taught in the curriculum per se, so students would have little prior knowledge and experience in the area. As students' interests have been shown to affect student learning, this increased interest may afford an increase in student learning and understanding in science and engineering fields.

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