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Abstract

Research has shown that an increase in students' interest in science and engineering can have a positive effect on their achievement (Baird, 1986; Eccles & Wigfield, 2002; French, Immekus & Oakes, 2005; Schiefele, Krapp, & Winteler, 1992; Schwartz-Bloom & Haplin, 2003; Weinburgh, 1995). Whereas many NSF-funded programs in materials science and nanotechnology have included efforts to develop curriculum materials for use in secondary or tertiary classrooms, relatively little work has been done to determine the topics that increase students' interest in science, engineering, and technology. As part of the work done by the National Center for Learning and Teaching in Nanoscale Science and Engineering (NCLT, 2008), we examined middle-school and high-school students' interest in topics and phenomena from the field of nanoscale science and engineering (NSE). Analysis of both quantitative and qualitative data suggested that students were most interested in topics and phenomena that related to their everyday lives, were novel, and involved manipulatives. Conversely, students were least interested in topics and phenomena they viewed as irrelevant to their lives, they believed they had learned previously, and in which they were not actively involved. These results were used to inform the development of curriculum materials for middle school and high school students aimed at enhancing the learning of NSE topics.

Keywords: nanoscale science and engineering education, nanotechnology, student interest, student motivation, middle-school, high-school

It is not surprising that motivational factors that influence an individual's level of interest in a field or content domain have been shown to play a crucial role in learning and development (Alexander, Jetton, & Kulikowich, 1995). Of potentially greater significance is the fact that an individual's level of interest has been found to be linked to deep-level learning as opposed to surface-level learning (Eccles & Wigfield, 2002; Schiefele, Krapp, & Winteler, 1992). Krapp, Hidi, and Renninger (1992) noted that learners use more elaboration and make more connections between concepts as they process information to which they are exposed when interest is triggered. Previous work therefore suggests that students' attention and learning can be enhanced by situations that promote an increased level of interest, which will subsequently be referred to in this article as "interest."

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A decline has been found in students' interest in the science courses that provide the foundation upon which engineering curricula build as these students progress through school and this decline in interest has been correlated with an analogous decline in test performance and achievement (Greenfield, 1997; Haussler & Hoffmann, 2002; James & Smith, 1985; Simpson & Oliver, 1985). Conversely, Weinburgh (1995) found that as students became more interested in science, their achievement levels increased across all ability levels. It is therefore incumbent upon those who teach science to consider their students' interest when designing lessons for the classroom. Thus, although teachers may be required to teach particular concepts based upon national, state, or local standards, they should contextualize lessons on these concepts so that they are tailored to the interests of their students.

In the last several years, the use of examples from Nanoscale Science and Engineering (NSE) has been proposed as one means of increasing students' interest in science (Chang, 2006; Foley & Hersam, 2006; Roco, 2003). Although NSE topics have not been a part of traditional K-12 science curricula, they may be of potential interest to students due to the many interesting and novel phenomena that occur at the nano level. They also provide the basis for building a link between the material covered in introductory courses in science and the content of courses students who pursue careers in engineering and technology will encounter.

Defining Interest

Interest has been defined as "a person's interaction with a specific class of tasks, objects, events, or ideas" (Krapp, et al., 1992, p. 8). It is "a psychological state that, in later phases of development, is also a predisposition to re-engage content that applies to in-school and out-of-school learning and to young and old alike" (Hidi & Renninger, 2006, p. 111). Researchers have divided interest into two forms: individual or personal, and situational. Individual interest is person-centered and lasts over an extended period of time, whereas situational interest is situation-centered but has the potential to develop into individual interest (Eccles & Wigfield, 2002; Hidi & Renninger, 2006; Krapp, Hidi, & Renninger, 1992).

A four-phase model of the development of interest that includes both individual and situational interest has been proposed by Hidi and Renninger (2006). This model progresses from triggered situational interest to maintained situational interest to emerging individual interest and finally to well developed individual interest as shown in Figure 1.

Characteristics that Influence Interest

Personal relevance has been found to have a positive effect on students' interests. When students find that a topic relates to their everyday life or to achieving a goal they have, they are more apt to be interested in the topic being discussed (Haussler & Hoffman, 2002; Sandoval, 1995; Schwartz-Bloom & Haplin, 2003). This increased interest has also been shown to relate to better recall and enhanced learning (Eccles & Wigfield, 2002; Hidi and Baird, 1986; Schiefele, 1999). Schwartz-Bloom and Haplin (2003) found that when high-school students are taught science concepts using material that is interesting and relevant to their own lives, significant gains in achievement can be made. This is consistent with the suggestion that information to be learned should be entrenched within contexts and applications that are meaningful and relevant to the students. The problem with achieving this goal is the difficulty of determining what topics are actually relevant to students at a particular grade level.

Prior knowledge or background knowledge may also have an effect on student interest in a topic (Bergin, 1999; Haussler & Hofmann, 2002). At times, student interest is increased by familiarity with a topic. Bergin (1999), however, has suggested that prior experience can also decrease an individual's interest in a topic.

The use of activities that involve physical manipulatives has been shown to have a positive effect on interest and learning (Bergin, 1999; Haussler & Hoffmann, 2002;

	Phase 1	Phase 2	Phase 3	Phase 4
	Triggered Situational Interest	Maintained Situational Interest	Emerging Individual Interest	Well-developed Individual Interest
Defined as	Short-term changes in affective and cognitive components	Focused attention and persistence over time to an activity/task	Beginning desire to re-engage with particular topics over extended time periods	Lasting predisposition to re-engage in a particular topic
Supported by	Externally supported through group work, puzzles, computers	Externally supported through meaningful tasks	Self-supported through positive feelings, stored knowledge, and curiosity	Self-generated through positive feelings and increased stored knowledge
Initiated by	Surprising information, personal relevance	Project-based learning, cooperative group work, one-on-one tutoring	Value in a particular task that reflects their interest	Long lasting interest for a particular topic

Figure 1. The four-phase model of interest development (Hidi & Renninger, 2006).

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Stohr-Hunt, 1996) because students become more engaged in the topic. The more involved students become in the task or topic, the higher their interest (Eccles & Wigfield, 2002; Hidi & Baird, 1986; Schiefele, 1999).

Novelty has also been found to influence interest (Bergin, 1999; Eccles & Wigfield, 2002; Haussler & Hoffmann, 2002; Hidi & Baird, 1986; Schiefele, 1999). Prior work suggests that people do not report an increase in interest if the stimulus is too familiar to them, or if the stimulus is too unfamiliar for them to understand (Bodner, 2001).

Methodology

Research Questions

This study was designed to investigate middle-school and high-school science students' levels of interest in a variety of NSE phenomena and concepts. The following research questions guided the design of the study, data collection, and the data analysis.

- What nano-scale science/engineering/technology topics and phenomena do students find the most interesting and the least interesting?
- What are the characteristics of the nanoscale topics and phenomena in which the students' are or are not interested?

Participants

Participants in this study were Midwestern students in middle schools and high schools from predominantly white, middle class, rural (n = 164) and suburban (n = 96) communities and from a culturally diverse urban community (n = 156). Table 1 provides a portrait of the participant demographics.

The high-school students in the rural community were enrolled in Chemistry 1, Integrated Chemistry and Physics (ICP), or Advanced Placement Chemistry courses that were all taught by the same teacher. High-school students from the suburban community were all enrolled in Chemistry 1 courses taught by the same instructor. The urban community high-school students were enrolled in Biology or ICP courses taught by various instructors.

From this population, 40 students (12 rural, 11 suburban, and 17 urban) were selected for interviews based on their gender and academic ability levels in science as determined by the student's science teacher. Approximately equal numbers of male and female students were interviewed. The sample population was also divided into approximately equal numbers of students who had been identified as low, medium, or high achieving by their instructors. The source of quotations in the remainder of the article will be identified using RHS, SHS, or UHS to identify students from rural, suburban, or urban high schools, respectively, and RMS, SMS, or UMS to indicate rural, suburban, or urban middle schools, respectively. Students also will be identified as either male or female, and as low, medium, or high achieving on the basis of their science teacher's assessment.

Table 1
Survey participants

	Middle	High	Male	Female	Total
Rural	74	90	63	101	164
Suburban	55	41	40	56	96
Urban	19	137	76	80	156
Total	148	268	179	237	416

Data Collection

The students were introduced to a variety of nanoscale topics and phenomena through four manipulative activities and a series of nanoscale driving questions. A mixed-methods approach (Johnson & Onwuegbuzie, 2004; Tashakkori & Teddlie, 1998, 2003) was used to collect data. Quantitative techniques enabled the first author to collect survey data on interest from a large number of students, while the qualitative techniques allowed for a more detailed, in-depth follow-up of the survey data.

Quantitative data were collected using a three-point Likert-scale survey developed to evaluate students' interest in a set of NSE topics and phenomena. The term "phenomena" was used in the survey in the sense of describing real-world objects, systems, or events in a variety of contexts to make the key ideas plausible (Smith, Wiser, Anderson, Krajcik, & Coppola, 2004). The survey asked students to rate their level of interest as either not interested, kind of interested, or very interested.

The survey covered four NSE manipulative activities and a set of 11 driving questions designed to measure students' interest in learning about NSE or nanotechnology topics. The four manipulative activities that demonstrated NSE phenomena involved a waterproof material, a hopping magnet (Lorenz, Olson, Campbell, Lisenski, & Ellis, 1997), changes in the color of nanoscale gold particles (McFarland, Haynes, Mirkin, Van Duyne, & Godwin, 2004), and the effect of a surfactant on the ease of stirring a mixture of zinc oxide and water. These activities were designed as a context in which to determine students' interests in the phenomena, rather than to elicit student knowledge. The first author therefore provided support during the activities, but no explanation of the science behind the activities. A description of the four activities is given in Appendix A.

A "driving question" has been defined as a well-designed question used in problem-based science that is elaborated, explored, and answered by both students and their teacher (Krajcik, Blumenfeld, Marx, & Soloway, 2000). Each of the following driving questions used in this study is introduced by a single term that will be employed in subsequent sections of this article when referring to these questions.

1. *Atoms*: How do we know atoms exist?
2. *Penny*: If a penny is made of tiny particles (atoms), why doesn't it fall apart?
3. *Pencil*: What do a pencil, a diamond ring, a car tire, and charcoal have in common?
4. *Gecko*: How can a gecko walk upside-down on the ceiling?
5. *Gold*: When will gold no longer be the color gold?
6. *Aspirin*: How did aspirin stop my headache today and my fever last week?
7. *Machines*: What kinds of machines are small enough to fit inside a living cell?
8. *Window*: What can be done to keep a window clean, making sure water and dirt do not stick?
9. *Robot*: How can we make DNA act like a robot?
10. *Common*: What do styrofoam, fog, milk, Jell-O, latex paint, and steel have in common?
11. *CD*: Why does a CD have so many colors on the back? Do these colors have anything to do with the music stored on the CD?

The students were not expected to answer the questions on the survey; they were only asked to indicate the level of their interest in learning and understanding the answers to these questions.

Interviews

To further elucidate the results obtained from the responses to the quantitative survey, one-on-one interviews were conducted with a subset of participants. These interviews were designed to elicit student discussions about why they found particular topics and phenomena more interesting than others. The interviews explored the students' interest level for each item and asked students whether they could explain how the activities worked or whether they knew the answer to the driving questions. Students were also asked how they would change the activities and questions to make them more interesting as well as how to increase interest in their current science class. The interviews lasted between 20 and 40 minutes and were audiotaped and transcribed.

Data Analysis

The surveys were coded for level of interest in each phenomenon and each driving question. The mean score for each phenomenon and driving question was calculated after assigning a code of 1 to the response of "not interested," 2 to "kind-of interested," and 3 to "very interested." The surveys were also analyzed by determining the percentage of students selecting each driving question as their most or least favorite question.

The interviews were analyzed qualitatively in order to evaluate why students expressed a given level of interest. Through the iterative process of the constant comparative method, several emerging themes that governed student interest were identified based on common trends found in the transcripts (Patton, 2002).

Results

Results of the analysis of the most interesting and least interesting of the four activities and the 11 driving questions are discussed in this section. The themes that emerged using the constant comparative method (Patton, 2002) are also examined. An analysis is also presented of suggestions students made during the interviews for changing the questions and activities to make them more interesting and suggestions they offered for making their current science course more interesting.

Students' Selections of the Most Interesting Topics and Phenomena

Overall, the students were most interested in the CD, Gecko, and Machines questions, as shown by the data in Figure 2. This was true for the total sample population for all district types (rural, suburban, and urban) and for the total sample population for both middle-school and high-school students. When the data were analyzed by gender, the same questions were judged as most interesting by the males. Females, however, were more interested in the Aspirin question than the Machines question. Of the four manipulative activities, the students were more interested in the Waterproof and Easy-Stir activities than the Hopping Magnet and Changing Color activities across all district types, across all grade levels, and across both genders.

Analysis of the interview data indicated that students were more likely to be interested in activities or questions if they involved: (1) real-world objects or events, (2) topics that were viewed as novel, and (3) physical manipulatives with which the students were actively involved.

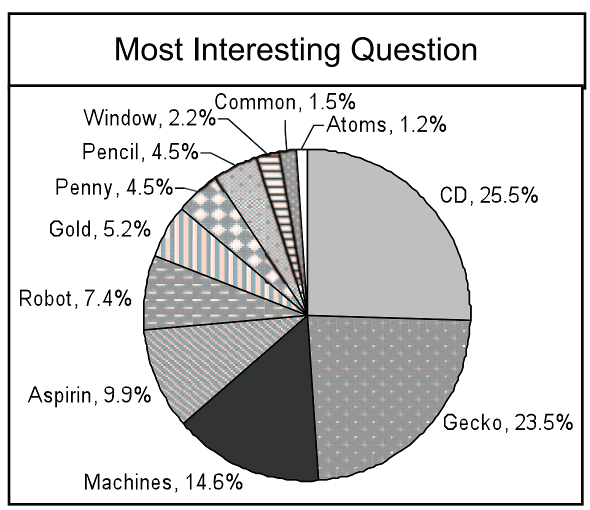

Figure 2. Percentage of all students selecting each of the 11 driving questions as the most interesting question.

Interest Due to Relevance to Real-World Objects or Events

As can be seen in the following excepts from student interviews, the students were interested in activities or questions that triggered their curiosity because they were relevant to their everyday lives, to societal issues, or to real-world objects or events:

> The ones that I was interested in most . . . are the ones that would actually affect my life and affect the lives of others. Things that, like, I can apply to everyday life are worth talking about. While the other things are things that I already know or . . . they don't matter so much. (RHS, low male)
>
> [Very interested in the Aspirin] because it's something that I actually can relate to and how like we have those problems and then like it goes away and we don't know why. (SHS, high female)

The students also responded favorably to questions or activities that aligned with their personal interests, even though the topic might not be interesting to other students, as seen in the following quotes from the interview data.

> [Most interested in Gecko] probably cause I like anything to do with animals. And I don't know, geckos are just cool like how they can stick to anything. Like he can climb up a flat surface and he has toes, but evidently, his toes are small enough that he can find something. Like it kind of reminded me of like a mouse, like how do they do that, you know? (RHS, high female)
>
> [Most interested in CD] because I like technology and you know I like to know how it works. I like to know how a computer works and how you know CD and all that works, just how it gets on the back of the CD and how it's encoded, how it's read, and how it works. (SHS, high male)
>
> [Very interested in Window because] I thought that was interesting cause I'd like to have that for my car, you know. You have dirt sticking to it and then the water runs on and you can't see though it, whereas with that technology, you'd never have to wash it and that'd be nice. So that's why I liked that one. (RHS, mid-high male)

Some students responded favorably to a particular question because it sparked a sense of curiosity. This was seen most often with the CD and Gecko questions, and was often the result of a connection between the question and previous personal experiences such as owning compact discs.

> [Most interested in the CD] because I've actually wondered why the colors were on CD and I don't know how what's stored on there and how they can do that or what contributes to it at all. I've always actually wondered [about] that myself. (RHS, low female)
>
> [Most interested in the CD because] I listen to a lot of CDs and so I've always wondered why there were a whole bunch of different colors on the back on those, so . . . (RMS, high male)

In general, when the activity or driving question related to the students' personal interest, general curiosity, or connection to their life, students felt that they would be more apt to want to learn the answer to the driving question or become more involved in the activity to discover an explanation for what was occurring.

Interest Due to Novelty

Students expressed an interest in questions that were perceived as novel primarily because they had not learned about the phenomena prior to this study. This theme presented itself in contexts in which something was not only new to the student, but also demonstrated something that the student had not expected.

> [Most interested in CD because] I don't know very much about that. I've never thought about that before. (RMS, mid male)
>
> [Most interested in Gecko because] I didn't think an animal could walk upside down on the ceiling. (SMS, high female)
>
> [Very interested in Waterproof] . . . 'cause like I've never really heard of like waterproof thing—like you can really waterproof something. And, I wanted to find out like how, like how it happens. (SMS, low male)

The combination of novelty and surprise was often found in comments from males who were interested in learning more about the Machines question:

> [Very interested in Machines because] yeah, I mean, to me that was amazing how we can get like little cameras that are small enough, and getting a picture, and what they do with it, you know. It's interesting; it's really amazing. It's really interesting how they can get it to work when it's that small and deal with it, with the engine being so small, I find that really interesting. (RHS, mid-high male)
>
> [Very interested in Machines] 'cause something that small, like cells are the smallest living organism and to fit something, for humans to make something that small with precision and put it inside of a living organism is just kind of like mind-boggling, cause it's so small and I would just like to know like what those machines would do. (SHS, high male)
>
> [Most interested in Machines because] it makes me curious about. . . . It makes me curious about what kind of . . . what kinds of machines are small enough to fit inside a living cell. Like, it makes me think, I guess. (RMS, low male)

One student commented that she was not interested in the Machines question because the topic was *too novel* for her to understand. When discussing the Machines question, she noted that she did not understand how it would work because someone would need to operate the machine and no one is small enough to do that.

> [Not interested in Machines because] I didn't think it was fascinating, because if you get a machine in there, then you're gonna have to get as small as a living cell to get in there to work it, to work the machine. (SHS, low female)

In general, students stated that they were interested in certain activities or driving questions because they did not know that "something could do that." However, the degree to which the topic or phenomena is novel must be considered, as indicated by the student who found the Machines question too novel for her to be interested in this topic. Our results suggest that students must have some understanding of the topic or phenomena being presented in order to stimulate their curiosity and desire to find out an answer.

Interest Due to Manipulative Nature of Activity

The students expressed particular interest in activities that involved physical manipulatives in which they were actively involved:

> [Very interested in the Easy-Stir because] I thought it was cool because you actually, you actually did something to the other side, so it's more than them just putting water in it, and keep on doing that, so . . . (RMS, high male)

Although the Changing Color activity was of low interest to many students, one student expressed his interest in this activity because he was involved in creating an immediate outcome:

> [Very interested in Changing Color because] it was immediate and that you could see and you changed something. And that was interesting a lot more than talking about the theoretical things like the atoms of uh, and what they're composed of, and how much they weigh, etc. And just it seems to me like one of those things for using chemical reactions to produce different colors and produce different reactions. (RHS, low male)

Students also commented on being interested in activities, in general, because they enjoyed taking an active role in the classroom:

> [Interested in the activities because they were] very involved. I mean, you got to actually got to do something and then see what was going on. Even if you didn't really know what was going on behind, I mean what was taking part, what was behind it. It was kind of like wow, because I didn't know that they had anything like that and it let me find out. (RHS, high female)

It should be noted that many of the students who responded that they were interested in the activities that involved physical manipulatives were from a district that, according to the students, did not perform very many activities or experiments in science classes.

In general, students indicated that they were more interested in activities in which they were able to physically manipulate an object and in driving questions for which they believed an activity could exist that would allow them to manipulate an object. They felt that this manipulation allowed them to figure out the answers, which would enhance their interest.

Students' Selections of the Least Interesting Questions/Activities

Overall, students were least interested in the Atoms and Window questions and the Changing Color and Hopping Magnet activities (see Figure 3). This was true for all groups of students, regardless of district, grade, or gender. The students noted that they were least interested in these topics and phenomena either because they did not find them relevant to everyday life, they already knew the answer, or they were not actively engaged in manipulating materials during the activity.

Uninteresting Because Not Relevant to "My" Life

The students were not interested in questions and activities that did not seem relevant to their individual lives or did not trigger their personal interests. The Windows question, for example, was not particularly interesting to the students

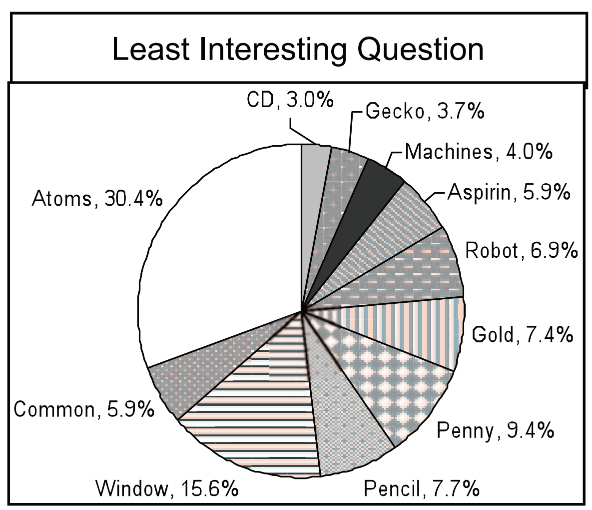

Figure 3. Percentage of all students selecting each of the 11 driving questions as the least interesting question.

because they did not believe that this new technology would benefit them in their lives:

> [Least interested in the Window because] umm . . . I don't know, I just felt that was kind of, I mean it would be neat if we had windows where you don't have to dust them and clean them for fingerprints, but at the same time, I could just get water and wash it off myself, so I wouldn't really need to know that, or feel the need to explore that, I guess. (SHS, low-mid male)
>
> [Not interested in Window because] like what can be done to a window to make sure water and dirt don't stick, it'd kind of be something to see, but it's not really useful to have something like that. (RHS, high female)
>
> [Least interested in Machines because] I mean it's interesting, but not as interesting as what I personally like and stuff like that. (RMS, low female)

Overall, students were not interested in a topic or phenomenon if they did not find it relevant to real-world objects or events, to their daily lives, or to something they would encounter in the future. The less a topic or phenomenon was viewed as being related to everyday life, the less the students were interested in discovering an explanation of an activity or an answer to a driving question.

Uninteresting Because I Already Knew the Answer

The students were not interested in questions or activities in which they believed they already knew an answer, or had been taught the answer to the question previously. This category also contained statements by students believing the question or activity was an "old type" of science, rather than something that was new or novel. This became particularly evident in the reasons that students provided for why they were not interested in the topic of Atoms.

> [Not interested in Atoms because] I think it's just because since I've sat in 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. (SHS, low female)
>
> [Not interested in Atoms because] umm, last year we did a whole thing on atoms and I just thought, you know, I already know that atoms exist. I know mostly a lot of stuff about those, so, I just didn't find anything exciting about it. (RMS, high male)
>
> [Least interested in Atoms], yeah, 'cause you kinda just know they're there. So it's not, it's not like umm, oh, what does everything mean. You just kind of learn so that, and it's not really that exciting because you know they're there and what they do. (RMS, mid female)
>
> [Not interested in the Waterproof because] well, I pretty much already know how that works, kinda. (RHS, mid male)

In general, the students' level of interest declined when they believed they had heard the information before and were not interested in learning about it again or exploring it in more detail. The more the students felt they knew about a topic, the less interested they were in exploring the topic in more detail. A fine line seemed to exist between knowing just enough information for the students to want to learn more, and students believing that they already know the information they needed, in which case they lost interest in the topic.

Uninteresting Because I Am Not Very Involved

The students were not interested in activities in which they perceived they would not be directly involved, either because they did not see much happening or because they did not have much to do during the activity.

> [Not interested in Changing Color because] I just didn't find it that interesting 'cause, I don't know, it didn't really do much, like it just kind of, like the color change. (RMS, high female)
>
> [Not interested in Changing Color because] it went from a red to a like a purple or a little darker and, I don't know, it just didn't seem like much happened. (RHS, mid-high male)
>
> [Not interested in Changing Color because] well really all I saw was a color change and there's a lot of different experiments that, you know, have a different color change, so I wasn't really sure what was going on, but I just saw a color change. (SHS, high male)
>
> [Not interested in Easy-Stir] because all we had to do was stir it. It wasn't like . . . exciting. (RMS, low male)

Students who were not interested in the Changing Color activity expressed the opinion that the color change was not exciting or interesting because it was not drastic. One student stated that although he was not exactly sure what was going on, it was just another color change and he had seen "lots of" experiments with color changes.

Students suggested that they would be more interested in the activities that were completed during class if they had been more involved in manipulating the materials being used. They also indicated that they wanted to observe drastic changes rather than subtle changes during the activities.

More Interesting If . . .

During the interviews, the students often commented on ways to make them more interested in the questions and activities described in this study, or in their science class, in general. Based on the results discussed so far, it is not surprising that they called for topics that were more relevant to their everyday life and involved more experimentation or hands-on activities.

They were specifically interested in everyday things that were relevant to people in their age group.

> [More interested in the questions if you] work them so like I could interact with them in everyday life that I do as a normal, however you define normal, human being. Like, put that into my everyday life then I might be a little bit more interested in it . . . the more (questions) relate to our everyday life, 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 homework, like we can put it to our lives. (SHS, mid-low male)
>
> [More interested if you] basically just relate it more to like our age and like things that we know. (SHS, high female)
>
> [More interested in science if] umm, I'd like to see, it annoys me about all the stuff we talk about, like the electrons and stuff, it all seems so flimsy, so theoretical, that like and umm, and I think I'd like to see a lot more of the practical application of chemistry. Like what you can use to advance your life. (RHS, low male)

The students also noted that they were more interested in learning about topics when they were able to see and interact with the phenomena, through experimentation or hands-on activities, rather than just talking about the topic and doing mathematical problems.

> I don't know, 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. (SHS, low-mid male)
>
> lots of labs that actually apply to what we're really doing and that aren't very time consuming. . . . It's kind of learning from all the class work and actually get to see. There's a lot that are involved in labs too. Like you have to read and follow directions, and it gets you thinking more, than like homework, or whatever when you just tune out. Like the hope is, I want to find out what happens and I've got to do it in order to find out what happens. (RHS, high female)

The students expressed the belief that there would be more thinking and learning if the amount of experimentation were increased because they would be active learners who would be more involved in figuring out what is actually happening rather than passive learners who were being told the answer.

Discussion

Three major themes emerged in this study that characterize students' interest in the introduction of NSE topics and phenomena into the middle-school and high-school curricula.

Assertion #1: Students Are More Interested in Nanoscale Science and Engineering Topics and Phenomena that Are Relevant to Real-World Objects or Events Or to Their Daily Lives.

The students in this study were more interested in NSE-related activities and questions if and when they were able to see a connection to their personal interests or to their everyday lives. They believed that relating topics, in general, to their everyday lives would significantly increase their interest in their current science courses. This result is consistent with prior work that suggests a relationship between the extent to which students can relate to a topic and their interest in and willingness to learn material being presented (Brooks & Brooks, 1993; Haussler & Hoffmann, 2002; Sandoval, 1995; Schwartz-Bloom & Haplin, 2003). Our results suggest that contextualization, which places material to be learned within the context of the students' everyday life, personal interests, and/or general curiosity, can lead to an increase in the students' interest in learning.

Whereas prior work has emphasized the role that examples from everyday life can play in increasing student interest in a topic (Haussler & Hoffman, 2001; Sandoval, 1995; Schwartz-Bloom & Haplin, 2003), the results obtained with the Gecko driving question suggest that enhanced student interest can be achieved using examples of real-world objects or events that are by no means part of the everyday life of the students we interviewed.

Assertion # 2: Students Are Interested in Topics They Perceive as Novel, Rather than Topics About Which They Have Prior Knowledge.

The students in this study tended to be interested in NSE-related questions and activities that seemed to be novel to them, which is consistent with research on characteristics that have an effect on students' interest (Bergin, 1999; Eccles & Wigfield, 2002; Haussler & Hoffmann, 2002; Hidi & Baird, 1986; Schiefele, 1999). It should be noted, however, that novelty worked best when the topic was something that was neither too familiar to the students nor too foreign.

This study suggests that sense of novelty is related to prior knowledge. Students who perceived they possessed significant prior knowledge of a topic were not interested in further investigation of this topic. These results are consistent with the work of Bergin (1999), who argued that the amount of interest a person will exhibit decreases as the amount of prior experience with the topic increases. This result is particularly relevant to the field of nanoscale science, engineering and technology because this is not likely to be material with which students are overly familiar.

Assertion #3: Students Are More Likely to Be Interested in Topics They Experience and When They Are Actively Involved in Thinking About and/or Visualizing the Topic Using Physical Manipulatives.

The students in this study noted that they would be more interested in questions, activities, and science classes in general, if there were more hands-on activities and experiments. The students did not want to just manipulate materials, however; they said that they would be more interested in a topic if they had to think about it and visualize the process first-hand. The relationship between the students' level of interest and the extent to which they were involved in a question or activity is consistent with prior work that suggested a direct connection between the level of students' interest in a topic and the level of their activity (Hidi & Baird, 1986; Schiefele et al. 1992; Eccles & Wigfield, 2002).

Conclusion

In general, students in this study were more interested in a question or activity if they viewed it as relevant to their everyday life or to their personal interests. Questions or activities that were novel also triggered interest for many students who wanted to learn about something with which they were unfamiliar or that might, at first glance, seem unlikely or impossible. Novelty was strongly related to prior knowledge, inasmuch as the students were less interested in learning about topics with which they were familiar from prior classes. The students were also most interested in hands-on activities that required them to do more than just follow directions or manipulate equipment or chemicals. They wanted to have to think and figure out explanations, as opposed to follow directions or to be told the answers in a lecture. By taking these themes into account, curriculum designers and teachers may be able to create curriculum materials that increase student learning as a result of triggering student interest in the material.

The results of this study suggest that students' interest in science might be increased by incorporating examples from NSE into the classroom. The advantage of NSE topics and phenomena for increasing student interest might be due to a combination of their prominence in today's society in the form of consumer products, advertising, popular media and books; the perception that these topics are novel; and the fact that students are unlikely to view these topics as having been learned in previous coursework.

Appendix A

Description of Manipulative Activities

In the Waterproof Material activity, students compared a traditional pair of khaki pants with a pair of Nanotex® khaki pants. After liquid was poured on each pair, students were asked to respond by describing what they saw. They observed that the old pair of pants absorbed the liquid, while the Nanotex® pants repelled the liquid.

In the Hopping Magnet activity, one side of a flat refrigerator magnet was cut off, and then dragged across a larger magnet in two directions. The students then cut a piece of the refrigerator magnet off the bottom and dragged it across the larger magnet in two directions. The students were asked to describe what they observed. They then dragged the piece from the bottom of the refrigerator across the larger magnet in a third direction to have the piece of refrigerator magnet "hop."

In the Color Changing activity, students were given a vial that contained 13 nm gold nanoparticles in an aqueous solution. They were then asked how they could change the color of this red solution. About 2 mL of water was added to the vial by the students, which produced no change in the color of the solution. The students then added sodium chloride to the solution, which changed the color of the gold nanoparticles from red to blue.

In the Easy-Stir activity, students were given a small amount of zinc oxide powder in a paper cup and asked to figure out how to make it look like paint. The students added about 2–3 mL of water to the cup and stirred to form a "clumpy" suspension. Half of the students then added 6 more drops of water, while the other students added 3 drops of the surfactant Darvan C-N. Students who added more water saw no change, while those who added the surfactant were able to make a suspension that looked more like "paint."

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