NanoSense: Introducing High School Students to Nanoscale Science

The design and implementation of a nanoscience curriculum, and challenges and implications for the future of nanoscience education

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Need

Nanoscience is the study of phenomena at the nanoscale (1-100 nm), where properties differ significantly from those at a larger scale. There is a need for nanoscience education in secondary grades, both to increase students' scientific literacy and to prepare them for further study in the field. Nanoscience education can also introduce an interdisciplinary element into the disjoint high school curriculum and provide compelling, real-world examples of science in action.

Goals and Approach

The goal of the NanoSense project is to help high school students understand the science concepts that account for nanoscale phenomena and tie these to the core scientific ideas they work with in traditional curricula. Working closely with chemists, physicists, educators, and nanoscientists, we have begun to define core nanoscience concepts and learning goals, organize these into coherent teaching units, gather and validate the content to be taught, design activities, generate materials, and test the curriculum in the classroom. As part of our participatory approach, we also hosted a workshop for nanoscientists, science education researchers, college faculty, and industry leaders to discuss issues in nanoscience education, including core nanoscience concepts (see Table 1), the role of hands-on and simulation-based experiences, and the preparation of teachers and students.

Table 1. *Core nanoscience concepts identified by workshop participants.*

1. Role of scale in all variables (e.g., size, number, forces, properties, time).
2. Role of energy (e.g., interparticle interactions, scale of energy and power).
3. Quantum principles and probability (e.g., quantized energy, tunneling, uncertainty of measurement).
4. Relation between structure and properties (e.g., nanotubes, thin films, quantum dots).
5. Role of surface phenomena in determining properties (e.g., surface chemistry).
6. Unique form of properties at the nanoscale (e.g., electromagnetic, mechanical, optical)
7. Self-assembly (e.g., bio-nanotechnology, crystal structures).
8. Control of fabrication (e.g., tools, processes, metrology).

Instructional Materials

Using the design features shown in Table 2 as our framework, we have built two initial units:

- **Size Matters** is an introduction to nanoscience, focusing on interesting applications of nanoscience, the unique properties of the nanoscale, and the tools used to make and study nanoscale objects.
- **Clear Sunscreen** focuses on why zinc oxide nanoparticles block UV light but are transparent to visible light.

Each unit opens with essential questions that drive the learning and then includes a collection of active learning experiences (e.g., labs, visualizations), student readings, PowerPoint presentations for leading class discussions, student worksheets and quizzes, and performance assessments. Teachers are provided with lessons plans and can select among the materials provided. Each unit spans about ten 50-minute classroom periods if all materials are used. Future units will focus on nanofiltration and clean energy.

Table 2. *Key NanoSense design features and their use in NanoSense units.*

Key Design Feature	Example from NanoSense Units
Situate the units in a single discipline (chemistry) to facilitate adoption in the existing high school structure.	Lessons assume some knowledge of atomic models, ionic and covalent bonding, emission of light by gases, etc. (Clear Sunscreen)
Center the units around exciting applications as a "hook" for students.	Science fiction story illustrates how nanotechnology might affect their lives in the coming decades. (Size Matters)
Guide the units with essential questions.	Why can some sunscreens block harmful UV light but let visible light through? (Clear Sunscreen)
Elaborate core science concepts and view them through a new lens.	The "Unique Properties" labs illustrate effects related ratio of surface area to volume (e.g., catalysis). (Size Matters)
Make explicit ties to biology, physics, material science, and engineering.	Slide presentation and performance assessment explore nanoscience applications in a variety of disciplines. (Size Matters)
Include visualizations of molecular entities and interactions generated and manipulated by students.	Students generate animations of the scattering of visible light by nano- and large-size particles of zinc oxide. (Clear Sunscreen)
Highlight the important features of the nature of science (inquiry process, use and limitation of models, etc.).	The "Black Box" activity considers the limitations and challenges in using probes to "see." (Size Matters)

Implementation

The Size Matters unit was pilot-tested with 2 teachers and approximately 90 students in three high school chemistry classes in the San Francisco Bay Area in May and June 2005. The teachers were given the full set of Size Matters curricular materials and asked to spend a week of class time on the unit. The Clear Sunscreen unit was pilot tested with approximately 30 students and 10 teachers in an all-day teacher-student workshop at San Jose State University in February 2006.

Findings

Based on our experiences designing and implementing NanoSense curricular units, we have identified three main challenges in developing nanoscience curricula:

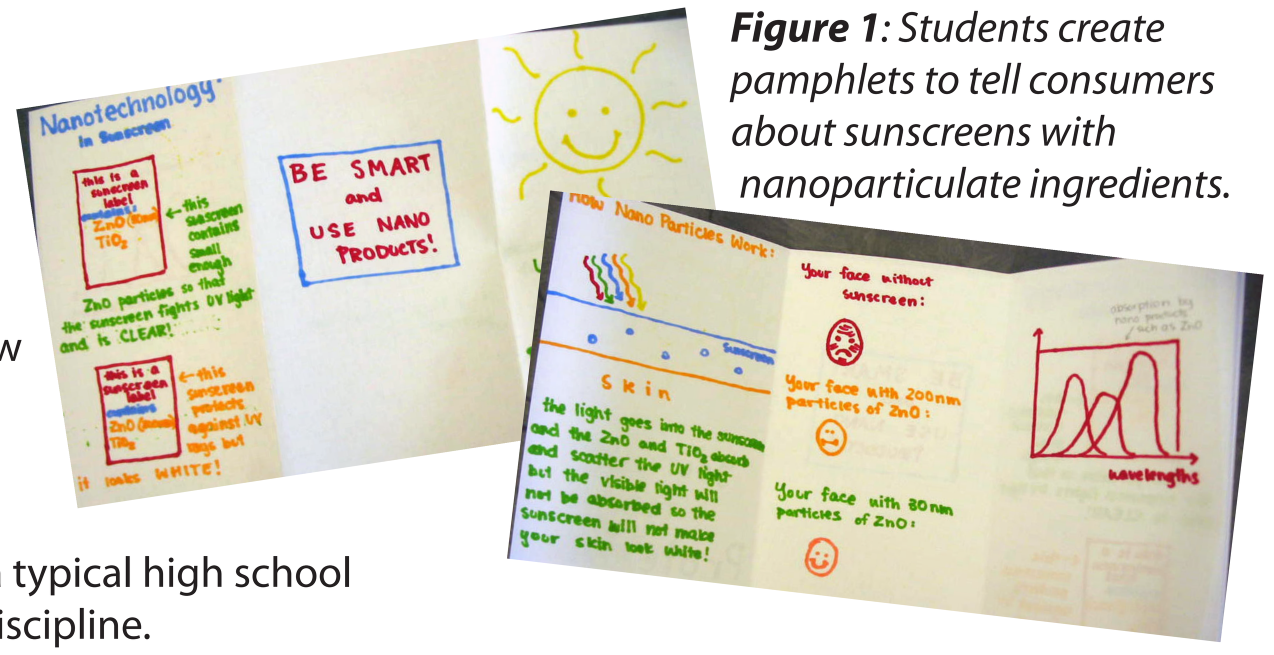

Figure 1*: Students create pamphlets to tell consumers about sunscreens with nanoparticulate ingredients.*

1. Defining the curriculum for a new and evolving area of scientific study.
2. Situating an inherently interdisciplinary science within a typical high school classroom that focuses on one discipline.
3. Developing teacher support materials for content that is novel and involves new modes of thinking.

Challenge 1: Defining the Curriculum

The first challenge is to determine the important things to include in a curriculum. Agreeing on a few central concepts through discussion and debate is an important first step in making sure that curricula meet the needs of the many stakeholders involved. Another challenge is to figure out how the identified pieces fit together and how to organize the curriculum. Should it be topically based around applications, organized by underlying themes, or structured around content topics within traditional scientific disciplines? Our work suggests that organizing units around content topics helps students connect their prior knowledge to the new information. A third challenge is finding reliable and verifiable information in a rapidly evolving area. For example, in the literature we found numerous terminology differences and nine different explanations that contradicted each other on various fronts regarding whether zinc oxide blocks UV radiation by absorbing or scattering the radiation. There are few common frameworks for understanding the central science––particularly ones that are understandable at a high school level.

Challenge 2: Situating the Science

We are targeting our materials for high school chemistry, but in our pilot studies we saw that knowledge of physics and biology are very helpful for both teachers and students in understanding nanoscience and its applications. This raises the question of whether nanoscience is best taught toward the end of the general high school science sequence. Team teaching approaches could also be effective, but coordinating such efforts adds another layer of complication in getting the curriculum used. Another approach is to leverage student knowledge of other disciplines, which could also reduce some of the burden on the teacher. A final issue is how to help teachers figure out where the curriculum fits with what they currently teach. We have found it useful to provide teachers with alignment charts of where the curriculum addresses core science topics. In addition, providing teachers with multiple ways to use the materials and a "drill-down" structure for progressively greater depth of understanding enables adjustment for different levels of students.

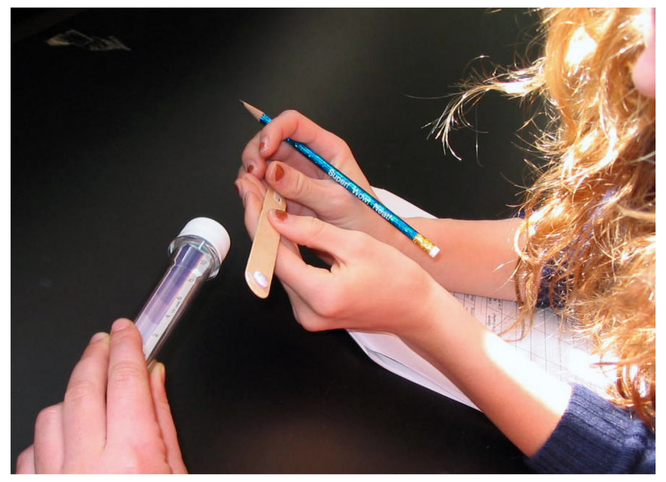

Figure 2. *Students testing the UV blocking ability of a sunscreen.*

Challenge 3: Preparing Teachers

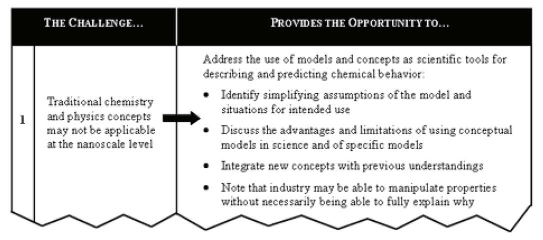

Figure 3. *Excerpt from teacher's guide addressing pedagogical challenges of teaching nanoscience.*

A final challenge is developing teacher support materials for an area in which the content is novel, reaches outside teachers' expertise, and requires new modes of thinking. Lack of familiarity with the content made it difficult for our teachers to stimulate discussion by asking follow-up questions and to identify and address student misconceptions. Developers must create materials that provide deep teacher content explanations, provide strong guidance for discussion topics and questions, and identify and highlight potential misconceptions. The novelty of the content, combined with the newness of nanoscience as a field, also raises pedagogical demands that some teachers may not be prepared to deal with. For example, teachers are not able to know all the answers to students' (and their own) questions, traditional chemistry and physics concepts are not always applicable, and many questions go beyond the boundary of our current understanding as a scientific community. To help teachers engage these challenges, we have recast them as opportunities to model the scientific process and provide concrete strategies for how to do so (see Figure 3). In this way, we aim to have teachers and students experience science in action as an empowering and energizing experience rather than as an exercise in frustration.

Conclusion

Despite the considerable challenges, it is possible to introduce new and evolving areas of science at the high school level. Cutting-edge science topics can highly engage students, reinforce core science concepts, and give students a better idea of how the traditional disciplines tie together.

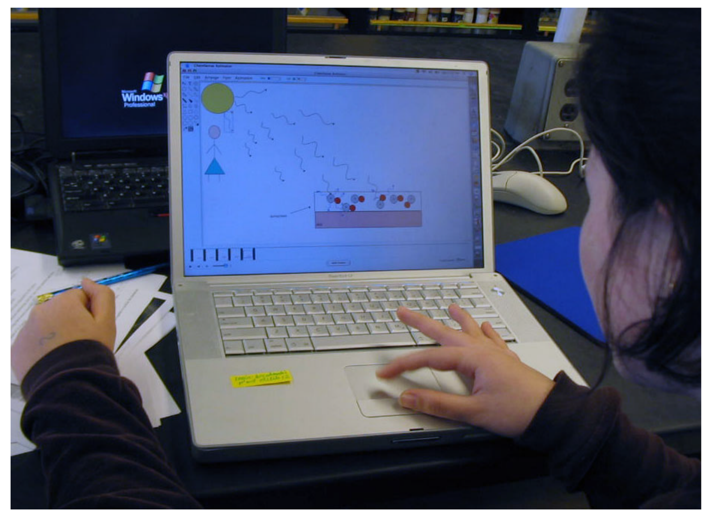

Figure 4. *A student uses ChemSense to animate the scattering of visible light by different sunscreens.*