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Teaching New Science: A Case Study of Nanoscience Education

Overview and Objectives of the Symposium

We are working in a period when new technological tools allow scientific researchers to look at new and complex phenomena. As first pointed out by Weaver (1948), the complexity of many of these phenomena is due to the large number of variables involved and the interrelations between these variables as part of a complex organized system.

The impact of these scientific advances requires a commensurate response in the educational community to help students develop new frameworks for making sense of the world. As science becomes more interdisciplinary (as we have seen in areas such as global climate change, ecology and genetics) we can no longer rely on the traditional ways of teaching science as a set of well understood, clearly depicted, standalone phenomena. We need to start to develop new approaches now in order to have materials and pedagogies well understood when the need for them becomes critical.

One important interdisciplinary area enable by new tools is the science and technology of the nanoscale. Nanoscience is the study of phenomena on the scale of 1-100 nanometers. It is an important area because of the many unique properties of matter at this size scale.
Given that 10 hydrogen atoms lined up are about 1 nm long, we can loosely describe the field as being concerned with “handfuls” of small molecules. Cells fall in this important size range as well. This size region is small enough that many of our models for bulk substances do not accurately predict the properties of materials, but large enough that quantum calculations are prohibitively complicated. Thus new models and ways of thinking must be developed in order to understand behavior at this scale.

The NanoSense project is one of a few innovative programs trying to address the question of how to teach nanoscale science at the high school level. This symposium will describe the NanoSense project, the challenges and opportunities that we have encountered in designing and implementing curricula for cutting edge science, and implications for the future of nanoscience education. These specific issues will be connected to the broader questions they raise about how to effectively incorporate the process of scientific inquiry into science education for new and evolving fields.

Structure of the Symposium

Chairperson: **Nora Sabelli, SRI International**

Presentations:

1. Patricia Schank, SRI International - *Teaching Nanoscience to High School Students: A Tale of the NanoSense Project*
2. Alyssa Wise, Indiana University – *Challenges in Designing Curricula for Cutting Edge Science*
3. Tina Stanford, SRI International - *Opportunities for New Pedagogy in the Classroom*
4. Anders Rosenquist, SRI International - *The Future of Nanoscience Education*

Discussants: **Joe Krajcik, University of Michigan**
Bob Tinker, Concord Consortium

Questions & Answers

Presentations

Presentation #1

Teaching Nanoscience to High School Students: A Tale of the NanoSense Project

Patricia Schank, SRI International

Including nanoscience education in the high school curriculum has the possibility to do more than bring nanoscience concepts "down" to the high school level. It can also introduce a much-needed interdisciplinary element into the disjointed high school curriculum, since nanoscience brings together concepts from physics, chemistry, and biology, as well as related areas such as materials science, technology and engineering. It can also provide a way to revisit core concepts from each of these domains, view them through a different lens and support understanding of the interconnections between the traditional scientific domains, reflecting the "unity in nature"(Roco, 2003). Furthermore, teaching cutting edge science provides the opportunity to let students experience “science in the making” versus “ready made science” (Latour, 1987) and explore motivating, compelling, real-world examples of science applications.

The goal of the NanoSense project is to help high school students understand the science concepts that account for nanoscale phenomena and tie these into the core scientific ideas that 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 classroom test the curriculum.

Key features of our approach include:

- Centering the units around exciting applications as a "hook" for students
- Situating the units in a single discipline (chemistry) to facilitate adoption in the existing high school structure
- Making explicit ties to biology, physics, material science and engineering
- Elaborating core science concepts (e.g. atomic energy levels) and looking at them through a new lens
- Highlighting the important features of "science in the making" including the inquiry process, the uses and limitations of models and the power of collaboration

This presentation will provide an overview of the NanoSense project, its goals, and the curriculum design and development process.

Presentation #2

Challenges in Designing Curricula for Cutting Edge Science

Alyssa Wise, Indiana University

Designing curriculum on the cutting edge of scientific research and applications is both exciting and challenging. In our work on the NanoSense project we are attempting to design curricula for high school students that gives them a sense of how things work at the nanoscale and prepares them with a new framework for unifying their science knowledge from the different disciplines.

We have found that there are many challenges in designing a cutting edge curriculum. The three main groups of challenges we have faced are:

- Defining the curriculum for a new and evolving (i.e. not fully understood) area of scientific study.
- Situating an inherently interdisciplinary science within a typical high school classroom that focuses on one discipline (i.e. chemistry).
- Developing teacher support materials for content that is novel for teachers (and, in fact, for many scientists).

Defining the curriculum

This challenge operates on three levels. First, we face the challenge of determining what are the core concepts that should be part of a "nanoscience curriculum" and identifying important topics and key applications which illustrate them. Furthermore, some of the core science concepts important to understanding nanoscience (e.g. quantum mechanics) are difficult and their inclusion in high school curricula needs to be considered carefully.

The second challenge is to figure out how these ideas fit together and how to organize the curriculum – for example, should it be organized by underlying themes, topically based around applications, or organized based on traditional scientific disciplines? The third challenge is finding reliable and verifiable information in a rapidly evolving area. For example, in our searches to understand the science behind nanoparticle zinc oxide sunscreens, we found nine different explanations in the literature, which contradicted each other on various fronts such as whether zinc oxide blocks UV radiation by absorbing or scattering the radiation. In addition, we found that the literature from different fields often uses different terminology or the same terminology in different ways. This highlights the primary issue that, as with any new science, our understanding is still evolving and there are few common frameworks available, particularly ones that are relevant at a high school level.

Situating the science
Regarding the second challenge, our intent is to develop a curriculum to embed in a typical high school college-preparatory chemistry class. Given the interdisciplinary nature of nanoscience, as we develop our materials, we consider what other science concepts (if any) students will have been exposed to, and in what other courses will they see the same or related concepts? We have also found that our partner teachers want to use the curricular materials in AP chemistry, regular chemistry, biology, physics, and interdisciplinary science. All these disciplines use different terminologies and focus on different aspects of phenomena. A final challenge relates to how to help teachers figure out where the curricula fits with what they currently teach.

Teacher professional development materials
The third area of challenge that we have encountered is in developing appropriate teacher support materials in an area in which the content is novel for teachers. We found that our original material in our first unit on unique properties of the nanoscale lacked sufficient detail to present the key concepts adequately to the AP chemistry students in the pilot classroom. We are currently working to revise the teacher support material to provide more background content for the teachers.

The novelty of the content to the teachers combined with its newness as a field also raised pedagogical demands that some teachers were not prepared to deal with. Helping teachers move from an expert "content-delivery" mode to a mode in which they join their students in a learning adventure and model the scientific process supports the National Science Education Standards (NSES) "Science as Inquiry" standards and is a challenge that we are currently working to address through our teacher support materials.

This presentation will describe the challenges encountered in designing curricula for cutting edge, interdisciplinary science and the strategies we are developing to meet these challenges.

Presentation #3

Opportunities for New Pedagogy in the Classroom

Tina Stanford, SRI International

Nanoscience work is on the cutting edge of scientific research and is expanding the limits of our collective scientific knowledge. Many of the same characteristics of nanoscience that present difficulties to designers also challenge teachers, but these challenges are manifest in different ways in the classroom. In our work on the NanoSense project, we have found that teaching nanoscience in the high school classroom forces teachers to move outside their comfort zones and for many teachers, challenges their traditional ways of running their classroom.

In our work with teachers implementing our NanoSense curriculum, we have found four specific challenges that stem from a teacher-centered didactic approach:

- Teachers were not able to know all the answers to student (and their own) questions
- Traditional chemistry and physics concepts are not always applicable at the nanolevel
- Some questions may go beyond the boundary of our current understanding as a scientific community
- Nanoscience is a multidisciplinary field thus draws on concepts from fields outside of teacher's primary area of expertise

To be a successful teacher of nanoscience requires taking the risk of not being the all-knowing expert and modeling the scientific reasoning process. In addition to being a necessary approach for a new and evolving field, showing that answers are not always clear cut and easy to find (if they exist at all) gives students an opportunity to deepen their understanding of the nature of science.

To help teachers move towards this approach and engage these challenges instead of seeing them as roadblocks, we recast each challenge as an opportunity to model the scientific process and provided concrete strategies for how to do so. In this way, we aimed to have teachers and students experience science in action as an empowering and energizing experience and not an exercise in frustration.

One particularly frustrating aspect of nanoscience is that traditional chemistry and physics concepts are not always applicable at the nanolevel. However, instead of being seen as a problem, this offers the opportunity to address the use of models and concepts as scientific tools for describing and predicting chemical behavior. All too often in high school science classes students confound explanatory models with the phenomenon they are being use to explain. Making the use of models explicit, discussing the assumptions which they are based on, and the limits of their use not only can help students figure out whether a model is applicable in a given situation, but more generally, is also a valuable lesson in the relationship of models to the phenomena they are used to describe.

Going one step further, we have not yet fully developed the models to explain behavior at this level and there are many examples in industry of situations where we are able to manipulate properties without necessarily being able to explain why. This is an important opportunity to involve students in exploring the nature of knowing: how we know what we know, the process of generating scientific explanations, and its inherent limitations.

Finally, nanoscience is a multidisciplinary field that draws on concepts from fields outside of teacher's primary area of expertise. We have been working primarily in chemistry classrooms and found that forays into physics and biology often place teachers in a position where their students know more than they do. For example, in one classroom we observed a chemistry teacher trying to explain the use of buckyballs as drug delivery systems struggle to draw a picture of a cell on the board. When possible, engaging and valuing student knowledge beyond the area of chemistry can help involve students in the class and help them create interdisciplinary connections. This also models the important process of working collaboratively in an emerging area of science.

This presentation will discuss teachers' experiences in the classroom with the challenges of teaching nanoscience and approach of reframing these challenges as opportunities to model science in action.

Presentation #4

The Future of Nanoscience Education

Anders Rosenquist, SRI International

As part the process of designing the Nanosense curriculum, we hosted a workshop at SRI International to discuss conceptual issues and needs related to incorporating the science and technology of the nanoscale in science education.

At the workshop, educational researchers and science educators (spanning high school, community college, and university levels), nanoscientists, science museum/informal learning specialists, and workforce development staff came together to:

- Identify core nanoscience concepts
- Explore the role of hands-on and simulation-based experiences in the learning process
- Discuss how to prepare teachers to teach in this new area
- Identify and document pathways (both formal and informal) for introducing students to nanoscience
- Recommend needs and directions for research related to nanoscience education.

The results of the workshop have important implications for thinking about nanoscience education including:

- Challenges to conceptual understanding of nanoscience
- Epistemological concerns
- Social implications

Challenges to conceptual understanding of nanoscience

The challenges to help students develop a conceptual understanding of nanoscience are both conceptual and practical; objects and concepts at the nanoscale are hard to visualize, difficult to describe, abstract, and their relationships to the observable world can be counterintuitive. This suggests the need to conceptualize a continuum of scales that can represent the non-observable phenomena in nature to help students integrate their views of matter at all scales.

Epistemological concerns

Some central epistemological ideas were identified in discussions at the workshop; these ideas can lead to better understanding of why science at the nanoscale requires a different educational approach. Two examples of such ideas are (1) small quantitative changes in some property can aggregate towards large *qualitative* differences and (2) all matter can be considered as either individual particles, as small groups of particles, or as large group of particles, each entailing different scientific models and theories.

Social Implications

A discussion of the social implications of nanotechnology as part of nanoscience education is important to give students tools to help them put in perspective the significant hype, positive as well as negative, found in most public discussions of the topic. Limiting education to “show and tell” awareness demonstrations could build the hype without providing the underlying context, whether that hype extols nanotechnology’s potential or decrys its dangers.

Taken as a whole, these results indicate that to be successful, nanoscience education will need to make a sharp departure from traditional ways of teaching. We are currently beginning to conceptualize an interactive system based on observable properties of matter that would work along a continuum of scales, providing representations of the non-observable and thus allowing students to integrate their views of matter at all scales.

This presentation will discuss the outcomes of the nanoscience workshop, their implications for the future of nanoscience education and current plans for a new interactive learning tool.

References

Latour, Bruno (1987) *Science in Action*. Cambridge: Harvard University Press.

Roco, M. C. (2003). Converging science and technology at the nanoscale: Opportunities for education and training. *Focus on Nanotechnology, 21*(10), 1247-1249.

Weaver, W. (1948) Science and complexity, *American Scientist* 36, 536-544.