Exemplary Science for Resolving Societal Challenges

Edited by Robert E. Yager

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Contents

Using Two of the Goals for School Science and One Category of Science Content as Advocated in the National Science Education Standards (NSES)

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The final version of the National Science Education Standards (NSES) was published in 1996 after four years of intensive debate, several trial editions, and the expenditure of seven million dollars of public funds. The focus for this monograph arises from two aspects of the NSES that too often are ignored as reforms are urged. One of these concerns two of the four goals that should frame reform efforts designed in science for preK–12 schools. The Standards also define eight categories of science content standards, enlarging the "playing field" beyond the traditional science "disciplines." The content category that is the major focus of this monograph is that students should have experiences with personal and social issues where the constructs of science can be used.

None of the goals specify content typically included in textbooks and the curriculum. Similarly, they have not affected state standards used to indicate what most achievement tests measure. The Standard's four goals for school science are to prepare students to

1. experience the richness and excitement of knowing about and understanding the natural world;
2. use appropriate scientific processes and principles in making personal decisions;
3. engage intelligently in public discourse and debate about matters of scientific and technological concerns; and
4. increase their economic productivity through the use of the knowledge, understandings, and skills of the scientifically literate person in their careers (NRC 1996, p. 13).

These are the goals we are asked to use as we change teaching, plan the continuing education of teachers, and consider ways to assess student learning. This monograph includes examples of actions designed to meet Goals 2 and 3 and the content focus on use of science skills and constructs to deal with personal and societal challenges.

Much attention is needed to prepare all citizens (including students of all school ages) to become involved with the problems and issues that affect human existence in homes, schools, and local government. This monograph was conceived to illustrate the centrality and importance of both Goals 2 and 3 and to make every teacher responsible for helping students improve their own lives as well as society in general. The goals and the content focus on realizing personal and societal problems are infrequently considered as worthy of attention or used to illustrate the use and understanding of science for all learners. These all are critical for a democracy to work! They also exemplify what is needed before reforms for school science can be undertaken.

Too often education goals go unnoticed or are merely conceived as broad statements used by administrators and state leaders to "glorify" teaching and learning. Few educators view the specific goals as something to consider before framing a curriculum, choosing instructional materials, and selecting instruments to assess student performance. Many teachers who are aware of the NSES have never read nor internalized the discussion of the goals and how they could and should be approached in their teaching. The work of Wiggins and McTighe (1998) is important in this regard. They urge all teachers to spend time in developing goals with their students and then immediately discussing and agreeing to the kinds of evidence that they could collect to indicate that the goals have been met. This is why assessment comes after teaching but *before* considering content in the NSES. Textbooks seldom, if ever, refer to every goal proposed in the NSES or to all eight categories of the science content standards.

The NSES do provide help with defining science content. Eight science content categories are recommended for use in meeting the goals in preK–12 schools. Once more there is little discussion and few examples of all eight in school curricula, state standards, or textbooks. Too many merely outline concepts anew from the basic disciplines of science, namely physics, chemistry, biology, and Earth and space science. Many chose to use NSES recommendations but ignore the unique and uncommon ones. The eight categories of content standards for science are

1. unifying concepts and processes in science,
2. science as inquiry,
3. physical science,
4. life science,
5. Earth/space science,
6. science and technology;
7. science in personal and social perspectives, and
8. history and nature of science.

The NSES recommend the consideration of all eight of these science content standards.

Inquiry was initially introduced in the early 1960s as a major new focus for school science. It was a new idea and even somewhat controversial. But today even textbooks claim a focus on inquiry. Another change introduced in the reforms of the 1960s was a focus on process skills. The American Association for the Advancement of Science (AAAS) developed a major K–8 program making process skills central to school science programs. Many continue to list the 14 skills scientists used to illustrate the meaning for inquiry. But when processes frame the curriculum completely, little reform is actually noted. That is why unification of concepts and skills is recommended first and as a "form" of content. Didactic teaching can succeed even when concepts and processes are defined and used to indicate specifically what students need to recite, though little real understanding and use usually occurs.

Technology is a word that remains confusing for many. Too many view it as computer technology, rather than a whole field dealing with the human-made world, encompassing engineering, medicine, and invention. In the 1960s Zacharias (the architect of the first of the alphabet courses, namely PSSC), advocated getting rid of all technology in textbooks, because "it was <u>not</u> science!" Now many see technology as being more interesting and vital for students than basic science. Further, in the real world of science there is major dependence on technology; it enables much science to be undertaken. This is very different from defining technology as the "applications of science."

The seventh category in the content standards—a focus on science from personal and social perspectives—is the theme of this book. Of special interest is the fact that such "content" is included for all three grade level groupings used in the NSES. It is also the means for illustrating ways that Goals 2 and 3 can be approached, as the content of science must include science from both personal and social perspectives.

This monograph includes 15 chapters written by diverse groups of writers, educators, and scientists who report on situations where Goals 2 and 3 are seriously considered and where science content is approached from personal and societal perspectives. The monograph illustrates how personal and social contexts have been approached in ways not found in mainline curricula or in the most-used science textbooks. Hopefully the 15 examples that follow will provide a new look at the Standards and encourage a broader view of science content anchored in our world. This can be done with less concern for merely covering the typical discipline topics. The authors report on exciting new strategies developed for meeting the goals while also considering the specific content recommendations central to reform. The chapters are diverse but all provide examples of real change and real reform.

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Linking Science, Technology, and Society by Examining the Impact of Nanotechnology on a Local Community

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Setting

In classroom conversation, a group of students talk about a new washing machine that uses nanotechnology to clean and sterilize clothes. The conversation follows:

S1: So this laundry machine, it puts in silver nanoparticles to like, clean the clothing that it washes?

S2: Yeah, I think so. I think I have the washer it's talking about but we never use…

S1: You have it? Isn't it like kind of expensive?

S2: We never use the silver part of it, so I don't know. And it's efficient with water. It saves water.

S3: Wait, how can you be using it without using the silver nanoparticles and then know whether or not it actually saves water?

This exchange took place during a unit that addressed the use of nanotechnology in a context familiar to these students. Goal 3 of the National Science Education Standards (NSES) calls for students to "engage intelligently in public discourse and debate about matters of scientific and technological concern" (NRC 1996, p. 13). The unit described in this chapter, "Clean—At What Cost?" (downloadable at *http://nano-cemms.illinois.edu/ssi*), focuses on addressing this goal through a series of activities that allow students to develop an understanding about the use of nanotechnology that has potentially direct effects on their lives. The unit was developed for middle and high school students for integration into the science curriculum at a variety of possible locations (such as in lessons on microbiology, properties of matter, or impact of science and technology).

Introduction

In order to "engage intelligently in public discourse" students need to be able to create and defend scientific explanations. This skill has been described as a key scientific practice (Michaels, Shouse, and Schweingruber 2008). We developed our materials to include the explanation framework of *claim*, *evidence*, and *reasoning* to provide the necessary support for students to develop this scientific skill (McNeill and Krajcik 2008; Novak, McNeill, and Krajcik 2009).

The unit opens with an introduction to products currently available that incorporate silver nanoparticles as an antimicrobial agent. Students are asked to research a product and present it to the whole class. Next, students conduct experiments testing the effects of silver nanoparticles on bacteria. This firsthand experience allows students to make connections between manufacturer's claims and their own experimental data. The concluding activity of the unit focuses on societal implications of this technology. Through a role-playing debate, students examine this technology from multiple perspectives.

These curriculum materials were developed by the Center for Nanoscale Chemical-Electrical-Mechanical Manufacturing Systems (Nano-CEMMS) at the University of Illinois. As a part of the center's goals, this National Science Foundation (NSF)-funded center is involved in educational outreach to prepare the next generation to deal with issues that result from advances in nanotechnology. The center brings together educators and researchers to collaborate and ensure that educational materials are engaging, meet state and national standards, and are scientifically valid.

Methodology

In this chapter, we report on the use of curriculum materials in two different schools. One school is a high school of approximately 900 students, located near a small midwestern urban community. The student body of this school is from diverse socioeconomic backgrounds. Students in two advanced placement biology classes and one general biology class participated in this study. The majority of these students were juniors or seniors in high school. The second school is a small private middle school of approximately 200 students within the same urban area. The students involved were members of a seventh-grade science class. Classroom data was collected and analyzed for trends in student learning connected to NSES goal 3. This data included pre- and posttests and classroom observations.

Description of the Curriculum Unit "Clean—At What Cost?"

Investigating Products

The unit begins with a whole-group discussion about a product that uses nanoparticles. A new washing machine, made by Samsung, washes clothes with water containing silver nanoparticles. As the clothes are being washed, the nanoparticles are deposited on the fabrics. As the clothes are being worn, the nanoparticles prevent bacteria from growing on the fabric. This should help reduce odors because it is primarily bacteria that produce the smell we associate with dirty clothes and body odor. This product was chosen specifically because it forms the basis of the societal implication piece later in the unit.

After this introduction, students are asked to identify and research another product that uses silver nanoparticles. Through the Project on Emerging Nanotechnologies website (*www.nanotechproject.org/inventories/consumer*) students search a database of more than 1,000 nanotechnology products. The search will yield several hundred products that use silver nanoparticles. Students are asked to prepare a two- or three-minute introductory presentation on their product to the whole class. During these presentations, students discover that the silver nanoparticles are used as antimicrobial agents in a wide variety of products.

Testing Nanoparticles

After the presentations of the products, a class discussion is used to question whether silver nanoparticles are truly effective as antimicrobial agents. Students are asked to inquire how these claims might be investigated, which leads students into the second part of the unit.

To investigate these claims, students are introduced to basic concepts of microbiology in a contextualized manner. Techniques such as spreading of bacteria and incubation are explained and demonstrated. An agar plate is passed around so students can view and touch the agar. This experience allows students to gain a sense of what agar is and how much pressure can be applied when spreading the bacteria without tearing the agar. Students then begin the lab investigation to test for bacterial sensitivity to silver nanoparticles. (A more detailed description of this lab investigation can be found in Muskin et al. 2008.)

We have found that this laboratory investigation provides opportunities to have in-depth discussions about valid experimental designs. As students design their investigations, discuss what a control is and why it is a critical component of each of their experiments. After the data collection and analysis phase of the investigation, students are able to evaluate whether silver nanoparticles are effective antimicrobial agents. This evaluation leads them into the third part of the unit.

Debating Societal Implications

How technology affects society is often overlooked in science curricula. In this unit, this important topic is addressed with the culminating activity: a role-playing debate. Students are introduced to a problem scenario. Students assume different roles within this scenario, and to debate the problem, they research information relative to their roles. They then debate with other students representing different roles. Finally as a group, a recommendation is made based on the information and arguments.

The scenario we used featured a hospital that was considering the purchase of washing machines that use silver nanoparticles. This scenario is based on a real product that students were introduced to at the start of the unit. As the linens are washed, some of the nanoparticles settle on them and provide a measure of antimicrobial protection. In the scenario, the hospital is considering using this machine to help combat possible patient bacterial infections and to save money by heating the water less than a traditional washing method would.

Students are given one of five roles: health care worker, patient, hospital purchasing manager, hospital legal counsel, or environmental regulator. Each student receives information and a set of concerns unique to their roles. For example, students representing the health care workers are given statistics on hospital infections of patients by bacteria; those representing environmental regulators receive information about the effects of silver nanoparticles on the environment. Students meet with other classmates assigned the same role. These groups read and discuss the materials provided to them and identify research questions generated from their discussions. After researching their questions, students develop an understanding of the complexity of the issues facing someone in their position.

After students are able to articulate the position and their own role, they are shuffled into new groups. A jigsaw strategy is used so that each new group has one member representing each of the five roles (Johnson, Johnson, and Holubec 1998). If groups cannot be made with one student per role, additional students might be assigned to the same role, or a role might be omitted from a group. These new groups represent a hospital advisory board. As this advisory board, they need to decide whether or not to recommend that the hospital adopt the laundering method using silver nanoparticles. Each student comes into the discussion primarily aware of his or her own role's position and quickly learns that there are other justifiable concerns. After each team decides on their recommendation, they briefly present their decision to the rest of the class, discussing some of the issues that arose and why they reached the conclusion that they did.

We have found that this scenario works well with the roles provided; approximately half of the groups recommend adopting the new laundry method, and the other half decide not to. We felt it was important to find an issue where different group recommendations resulted to reinforce the idea that not all issues clearly point to one outcome as better than another. After all groups have presented their decisions, the class uses this activity as the context for a whole-class discussion on how the risks and rewards of many issues do not point to a single correct decision. This unit begins to show students that scientific knowledge is fluid, and attention needs to be paid to how science is used.

Upon reflection, the authors noted that ways one teaches may unintentionally influence the perspectives of their students. This bias may lead to a particular outcome with respect to the debate. Teachers need to be aware of this potential bias so as to not influence students' discourse. Although it is impossible to completely eliminate personal bias, care should be taken when engaging in issues with multiple outcomes.

Results and Evidence of Successes

With post-assessment data, we have documented the learning that occurred as a result of student engagement in this unit. In examining students' responses, we identified three key themes linked to the NSES Goal 3. These themes are (1) developing awareness of different perspectives and potential bias, (2) the need for evidence to support a claim, and (3) the impact of a decision. In this section we highlight these themes by using student examples and articulate how they were developed during the enactment of the unit.

Theme 1: Developing Awareness of Different Perspectives and Potential Bias

This theme became evident as students analyzed different sources of data. This bias awareness allowed students to critically examine data they obtained for use as evidence.

> S1: I've learned that it can be hard to find completely objective information about scientific stories or reports from the popular press.

Students also realized that there were multiple viewpoints that needed to be considered.

> S2: It has shown me, although I already guessed, that different news sources show different sides of an argument.

> S3: It shows that there are many more sides concerning the story, i.e., many more factors than what the press usually reveals.

The majority of the students shared the understanding that these multiple viewpoints were warranted.

> S4: [The "Clean—At What Cost?" unit has] given me a broader view of the positives and negatives of scientific advances. The positive effect is that it replaces any conventional cleaners but can have negative effects on the environment.

Students learned that evidence could be used to support differing perspectives. One student demonstrated his understanding of this complexity by saying:

> S5: [The new washing machine] has positive and negative ideas associated with it. It seems to lower cost and increase efficiency but it also may damage the environment.

The students began to examine all sources of information and consider what bias the sources might have. Some students generalized this concept beyond the unit and stated that they now routinely look at the source of data as they consider its validity.

> S6: Now, when I hear scientific reports, I think about how in the nanotechnology unit we found that scientists who are trying to prove something might be a bit more biased, so I look at who wrote the scientific reports/stories.

Students realized that they needed to evaluate the source of the data and look for bias based on the source.

> S7: It has affected how I think. I now see that reports can be influenced by personal views on a product and one needs to do a lot of research before forming an opinion.

One interesting result observed during the preparation for the debate was the manner in which students judged the validity of information. For example, one of the groups assigned the role of hospital manager was provided the website of the washing machine manufacturer. They quickly realized that the manufacturer might be a biased source and checked the validity of many of the claims made by the manufacturer. Other groups exhibited this behavior as well.

An additional example of students examining source bias was in the discussion of a middle school group assigned to the role of health care worker. While researching, this group found information contributed by an individual with a PhD. They assumed the information was accurate and unbiased. Later, they were surprised when they came across several sites with contradictory information to the first site. They then looked more closely at the authors of the sites and realized that the first site was hosted by an activist organization. They were amazed that they had been so strongly taken in by the first site. This group of students became much more careful in looking for possible bias.

Theme 2: Need for Evidence to Support a Claim

The unit highlighted the use of scientific explanations incorporating claim, evidence, and reasoning. This emphasis of scientific explanations was a component of all activities in this unit. The use of scientific explanations by students emphasized that they need evidence to support their ideas. It became apparent that as the students prepared for the debate, they began to develop a better understanding of why they needed to have data to use as evidence to back up their claims. Students saw that without evidence, unsupported claims can easily (and wrongly) be made.

> S8: The results can be used to tell people that what they hear is not always true.

Students viewed evidence as a way of supporting a claim in their debate. The use of evidence prevented the discussion from becoming a "he said, she said" debate. Instead, it allowed students to focus on supported arguments and have a productive debate. This level of understanding is reflected by the student's statement about the need of evidence to support a claim and letting the audience decide if the evidence was sufficient.

> S9: Well, you should show your results and state your findings. Maybe then you can change some minds.

Students realized that the use of evidence goes beyond just trying to change someone's opinions. Instead, evidence was used to evaluate the claim and its supporting evidence in order to formulate a reasoned group recommendation.

S10: It [evidence] tells about how they [silver nanoparticles] affect the environment and people. We can now decide whether or not to use silver nanoparticles.

Theme 3: Impact of a Decision

Through engaging in this activity, students realize that all decisions have impacts and that these impacts might not be good or bad but rather contain elements of both. In addition, students start to realize that through solving one problem, another is often created. A student made this observation in the statement below:

S11: With our results from the activity, you can see that some of the ways we fixed problems with the silver created new problems that science would have to fix.

Students realized that there were conflicting impacts that needed to be taken into account in any final decision. Students articulated an understating that some views focused on the good of the patient and not the good of the environment and vice versa. All of these different concerns needed to be considered in the final decision-making process. One student articulated the conflict when she wrote:

S12: Nanotechnology can change everyday lives. In the washing machine example, sterilized clothes were beneficial to the people but not necessarily to the environment. Nanotechnology had both good (clean/healthy stuff) and bad (harming good things in nature) qualities just like everything else.

Some students went further in their understanding and recognized that often we do not have enough evidence to know all the positive and negative effects.

S13: It has made me realize that though we try to find the answers to everything, we may not always have enough information to do so. Sometimes we just have to make smart, educated guesses and be happy with how that turns out.

Conclusions

As a result of this unit, students engage critically in a discussion about issues that potentially affect them, the community in which they live, and the larger society, as called for in the NSES. As curriculum developers, we believe that to engage students in scientific discourse around an issue with societal implications, it is critical to select a genuine context and use an inquiry-based approach in the design of the materials.

In developing this unit, we selected an issue involving nanotechnology to serve as the real-world context. The activities were designed to allow students to develop a scientific understanding of the issue through multiple inquiries. This type of curricular approach has been shown in the literature to improve student attitudes and their learning of science (Bennett, Lubben, and Hogarth 2007).

The sequence of activities allowed students to engage in multiple inquiries into the applications of silver nanoparticles. In this unit there was a range of activities that were student-directed and that engaged students in multiple scientific practices. These practices included designing and conducting an investigation, analyzing data, developing scientific explanations, conducting scientific research, and participating in scientific debate.

Nanotechnology lends itself to developing materials focused on interesting societal issues because of it only recently emerging in science and because of the promise it holds for the future as noted by Gardner, Jones, and Falvo (2009). Our collaboration with the center's researchers allowed us to be cognizant of both the positive and negative potentials of the use of these emerging technologies. These new technologies are often found at the center of societal issues and should be considered as rich contexts for future curriculum development.

Additional resources for this unit are available at *http://nano-cemms.illinois.edu/education* and at *http://nano-cemms.illinois.edu/materials*.

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