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Grand Challenges:

Nanotechnology and the Social Studies

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Science, technology, engineering, and math (STEM) education continues to receive considerable attention from policymakers and funding organizations, but many now agree that a focus on these disciplines alone represents an incomplete education for students. To truly understand the "grand challenges" of engineering, for example, students must grasp the social, political, historical and economic contexts in which these challenges arise. In a study published by Brad Maguth, social studies teachers in a STEM high school demonstrated how the social studies can serve as the "essential 'glue' that holds the STEM disciplines together."[1]

This article explores a multidisciplinary lesson on nanotechnology that can provide an effective means for teaching about both STEM and social studies topics. This approach encourages students to consider the "role that science and technology play in our lives and in our cultures," addressing NCSS standard 8 SCIENCE, TECHNOLOGY, AND SOCIETY.[2] The extraordinary promise of nanotechnology, however, is tempered by concerns about its social and ethical ramifications, providing a case study about the interconnected relationship between the sciences, technology, and our democratic society.[3]

Recently, I have had the opportunity to work with and evaluate the educational programs of the newly created ASSIST Nanotechnology Engineering Research Center at North Carolina State University.[4] The Center is aimed at using nanotechnology to improve global health. As a relative outsider (a social studies teacher educator, researcher, and a former high school history teacher), this experience has opened my eyes to the very real promise for multidisciplinary research and teaching related to STEM and the social studies. Although the Center is still in its infancy and it is too early to assess its education program, it does provide some curricular exemplars. Below, I provide a brief review of the social studies issues related to nanotechnology, including ethical, political, social, and economic issues. This is followed by an example learning activity.

STEM and the Social Studies: A Focus on Nanotechnology

What is nanotechnology?

As students begin to learn about the depth and range of the science surrounding nanoscience, they may encounter difficulty in determining an adequate definition of "nanotechnology." A quick search of the Internet turns up myriad definitions. To further complicate matters, there is a distinction between nanoscience and nanotechnology, connoting an emphasis on basic or applied science. According to the U.S. National Nanotechnology Initiative (NNI), "Nanotechnology is the understanding and control of matter at dimensions between approximately 1 and 100 nanometers (nm), where unique phenomena enable novel applications not feasible when working with bulk materials or even with single atoms or molecules."[5] Due in large part to advances in microscopy scientists have begun to understand and make use of the properties of materials at the nanoscale. [6]

Nanomaterials may already be part of your everyday life, appearing in luggage, bicycling helmets, sports equipment, food containers, batteries, fabrics, cosmetics, sunscreens, household products, TVs, laptop screens, and the catalytic converter in your car. According to NNI, "There already exist over 800 everyday commercial products that rely on nanoscale materials and processes."[7] For instance, the inclusion of nanomaterials may enable clothing to resist stains or dry more quickly and allow manufacturers to sell protective equipment that is lighter and stronger. Figure 1 (on p. 97) provides a high resolution glimpse of a nanocomposite used in a variety of household and industrial products.

One potentially important outcome of nanoscience includes changes in medicine and health care. Nanotechnologies might be developed to better diagnose, treat, and manage chronic health conditions and acute illnesses. The ASSIST Center envisions "a paradigm shift in health informatics enabled by wearable nanotechnologies that monitor individual health parameters and environmental exposures," allowing patients, doctors, and scientists to make connections between an individual's health and environmental toxins.[8] For example, nanodevices may be able to monitor environmental triggers to asthma, such as exhaust fumes.[9]

Nanotechnology and Society

There are several points of connection between the social studies and the study of nanotechnology, the most obvious being inquiry into the social, cultural, economic, and ethical dimensions. Nanotechnology, like most other recent scientific advances, does not fit neatly into a single discipline. Rather, the implications of this emerging technology have repercussions for our society and culture as a whole, making it a multidisciplinary field in need of a variety of perspectives and influences. For example, there are obvious social and economic benefits associated with advances in health care such as in the treatment of chronic disease, including dramatically reducing health care costs and prolonging the average life span. At the same time, these benefits may change our social relationships—as people live longer, they may marry later or retire later—and populations will likely increase.[10] To be effective, these nanodevices require the wearer to attach the device to the body (for example on a bracelet, adhesive patch, or on a tooth), giving rise to concerns about privacy and compliance. Another example of the multidisciplinary nature of nanotechnology focuses on efforts to improve the health and safety of farm workers. Research efforts are underway to devise effective strategies that monitor environmental exposure and develop more heat-sensitive nano-clothing to protect farm workers.[11]

According to Ronald Sandler, author of a report on the social and ethical issues related to nanotechnology, "Nanotechnology has tremendous potential to contribute to human flourishing in socially just and environmentally sustainable ways," yet its associated social and ethical issues must be "adequately attended."[12] A 2006 UNESCO bulletin, "The Ethics and Politics of Nanotechnology," clarifies the science of nanotechnology and addresses ethical, legal and political issues faced by the international community. The authors of the report noted the importance of identifying and analyzing ethical issues in relation to nanotechnology so that implications were clear to the general public, specialized groups, and decision makers.[13]

It is important for students to recognize that nanoscience innovation does not occur within a vacuum. Our approach to technological innovation and our responses to it as a society reflect our values. For example, in exploring the relationship between government and technological innovation, we can infer social norms and values. The government funds, regulates, and has the power to address ethical concerns related to science. Relevant to the social studies is exploring the interconnectedness between scientific innovation and democratic society.

Lesson Plan: Digital Documentaries Focused on Social and Ethical Issues of Nanotechnology

The following lesson plan, inspired in part by the work of Mishra, et al., explores the social and ethical issues relevant to nanotechnology.[14] It also builds on previous work connecting authentic intellectual work with technology-rich teaching and learning.[15] In this lesson, students create digital documentaries that address social issues related to nanotechnology. Ideally, social studies teachers would collaborate with science and technology teachers in their schools to simulate the work of multidisciplinary teams. The student-created documentaries should explore the affordances and limitations of nanotechnology to address various issues while focusing on relevant ethical, economic, social, and cultural issues.

1. Background knowledge: Begin by having students explore the topic of nanotechnology. There are many web-based and text-based resources available to help students separate myths about nanotechnology from the realities. The UNESCO bulletin opens with a list of both the probable and the improbable outcomes of nanotechnology.[16] Similarly, *Nanoscale Science: Activities for Grades 6–12* by Gail Jones includes a chapter titled, "Fact or Fiction: Exploring the Myths and Realities of Nanotechnology."[17] For additional resources, please see the side bar of web-based resources focused on nanotechnology.

2. Research and topics: Once students have a good working definition, they can begin to explore issues addressed by nanotechnology. These issues may have direct and obvious social and ethical implications, others may be more subtle. For instance some nanotechnologies, such as those in our clothes or household products, may lead to our personal reliance on these items, while others, such as bionic contact lenses may require the creation of new networks and infrastructures. Students might focus entirely on issues related to health and medicine, including the treatment of chronic disease, protection of migrant farm workers from pesticides, performance enhancing drugs or "radical human enhancement,"[18] and genetic modification. They may also examine the development of safe and efficient energy sources, nanomaterials in everyday objects, and the safe disposal of nanotechnology waste.[19] Teachers could ask students to choose a topic that aligns with one of Sandler's five types of social and ethical issues related to nanotechnology: "social context issues," "contested moral issues," "technoculture issues," "form of life issues," and "transformational issues";[20] or use the web-based case studies produced by the *Nanoethics on the World Wide Web: Helping Faculty Enhance Graduate Education* project as a starting point.[21]

3. Storyboarding: As students gather their research, they should brainstorm possible directions for their digital documentaries. Teachers can provide storyboarding tools for students to plan their documentaries. The website *Digital Docs in a Box* has excellent

resources to support students throughout the process.[22] Storyboarding is an iterative process and students will likely go through many drafts as they explore connections between nanotechnology, society, and ethics. Teachers should support students in this process by providing considerable formative assessment, especially regarding the content of the documentary.

4. Scripting: In addition to storyboarding, teachers might require students to write a screenplay or narrative. This can provide a script for the narration of the documentary and provide yet another opportunity for teacher feedback. Scripting provides an authentic connection to English language arts and will require students to craft a clear argument using evidence from their research. Again, teacher formative feedback is essential at this stage.

5. Production: Once students feel comfortable with their plans for their digital documentaries, they can begin the production phase. iMovie and Microsoft Moviemaker are two readily available software applications that students can use to create their documentaries. Some schools may offer more advanced film and editing systems as part of their media production curriculum.

6. Presentation and assessment: Once students have completed their documentaries, it is time to screen the movies in front of classmates, peers, or other school community members. A documentary film assessment rubric is available from *Digital Docs in a Box* at http://digitaldocsinabox.org/creating.html. In addition to teacher summative assessment of the student created documentaries, it is beneficial to allow for peer assessment and feedback. For instance, a classroom "film festival" might end with juried awards, based on a simple rubric, to the top three student-created documentaries. This might coincide with annual NanoDays festivals held across the country about nanoscale science and engineering.

Conclusion

The multidisciplinary approach to nanotechnology featured in this lesson plan emphasizes the important role of science within a democracy. Nanotechnology is one example of the myriad ways that scientific advancement can positively impact our society. As exciting as the potential of nanotechnology may be, there are also concerns about the ethical and social considerations that accom-

Web based Resources

Murphy Library: Science, Technology, Engineering, Math and Social Studies (STEMSS) **www.uwlax.edu/murphylibrary/departments/curriculum/stem/index.html**

Nanooze Magazine: Free Print or On-Line Magazine for Students and Teachers
www.nnin.org/education-training/nanooze-magazine

National Nanotechnology Initiative
Nanotechnology Timeline (beginning in the 4th century)
www.nano.gov/timeline
Resources for K-12 Students
nano.gov/education-training/k12
Resources for K-12 Teachers
http://nano.gov/education-training/teacher-resources

National Nanotechnology Infrastructure Network: Teacher's Guide to Social and Ethical Issues in Nanoscience and Nanotechnology
https://depts.washington.edu/ntuf/issues/docs/SEIteachersguideBassett.pdf

North Carolina State University: Nanoscale Science Education
www.ncsu.edu/project/scienceEd/

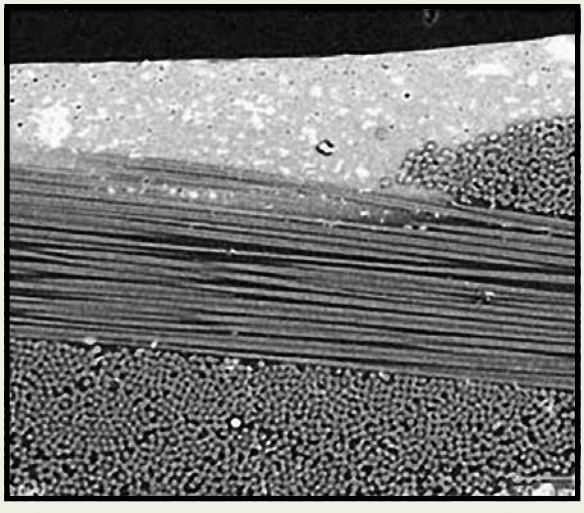
PBS Teachers: STEM Education Resource Center
www.pbs.org/teachers/stem/

Science Learning: Student Activity on Social Issues and Nanotechnology
www.sciencelearn.org.nz/Contexts/Nanoscience/Teaching-and-Learning-Approaches/Social-issues-and-nanotechnology

University of Wisconsin Research Experiences for Teachers (RET): Exploring the Nanoworld
http://education.mrsec.wisc.edu/Edetc/modules/index.html

The Scale of Things
http://nano.gov/nanotech-101/what/nano-size
http://nano.gov/copyrightinfo

Figure 1. **High Resolution Image of a Nanocomposite**



High-resolution image of a polymer-silicate nanocomposite. This material has improved thermal, mechanical, and barrier properties and can be used in food and beverage containers, fuel storage tanks for aircraft and automobiles, and in aerospace components. (Image courtesy of NASA.)

http://nano.gov/you/nanotechnology-benefits
http://nano.gov/copyrightinfo

pany these new advances. Rather than approach STEM education from a narrow, disciplinary perspective, teachers should collaborate to promote student understanding of the complex and multidisciplinary nature of scientific innovation. This not only promotes "trans-disciplinary thinking," but also allows for the "infusion of creativity in traditional 'analytic' curriculum like STEM disciplines."[23]

Notes

1. Brad Maguth, "In Defense of the Social Studies: Social Studies Programs in STEM Education," *Social Studies Research and Practice* 7, no. 2 (2012): 84.
2. Theme 8: Science, Technology, and Society, *National Curriculum Standards for Social Studies: A Framework for Teaching, Learning, and Assessment* (Silver Spring, Md.: NCSS, 2010), www.socialstudies.org/standards/strands.
3. Ronald Sandler, "Nanotechnology: The Social and Ethical Issues," (Washington, D.C., Woodrow Wilson International Center for Scholars, 2009), www.nanotechproject.org/process/assets/files/7060/nano_pen16_final.pdf, 11.
4. The NSF Nanosystems Engineering Research Center (NERC) for Advanced Self-Powered Systems of Integrated Sensors and Technologies (ASSIST), http://assist.ncsu.edu/, funded by the National Science Foundation, is part of a larger, concerted effort to fulfill the promise of nanotechnology—the United States National Nanotechnology Initiative (NNI).
5. National Nanotechnology Initiative, "Frequently Asked Questions," (NNI, Washington, D.C.), www.nano.gov/nanotech-101/nanotechnology-facts. For a more detailed definition of nanotechnology see: NNI's "What It Is and How It Works" www.nano.gov/nanotech-101/what;
6. "What's so Special about Nanoscience?" http://nano.gov/nanotech-101/special.
7. National Nanotechnology Initiative, "Benefits and Application," (NNI, Washington, DC), http://www.nano.gov/you/nanotechnology-benefits.
8. *ASSIST: NSF Nanosystems Engineering Research Center for Advanced Self-Powered Systems of Integrated Sensors and Technologies*, (Raleigh, N.C.: North Carolina State University),
9. For a more detailed discussion see Sandler, 2009, and Stephen W. Nicholas, Betina Jean-Louis, Benjamin Ortiz, Mary Northridge, Katherine Shoemaker, Roger Vaughan, Michaela Rome, Geoffrey Canada, Vincent Hutchinson, "Addressing the Childhood Asthma Crisis in Harlem: The Harlem Children's Zone Asthma Initiative," *American Journal of Public Health*, 95, no. 2 (February 2005), 245–249. There is some disagreement about the best approach to reducing childhood asthma, particularly in impoverished urban areas. Some are critical of the monitoring approach, favoring instead placing direct limits on exhaust emissions and the location of bus depots, etc.
10. Sandler, 2009, describes these as "form of life" issues, 43-48.
11. Shedra Amy Snipes, "'I Wore My Protective Equipment, but I'm Still Sick': Pesticide Protection and Health among Farmworkers," seminar presentation (December 13, 2012, Raleigh, N.C.).
12. Sandler, 5, 8.
13. UNESCO, "The Ethics and Politics of Nanotechnology" (Paris, France, UNESCO, 2006), http://unesdoc.unesco.org/images/0014/001459/145951e.pdf, 3, 4.
14. Punya Mishra, Danah Henriksen, and the Deep-Play Research Group, "Rethinking Technology and Creativity in the 21st Century: On Being In-Disciplined," *TechTrends* 56, no. 6 (November/December 2012), 20.
15. For a discussion of authentic intellectual work see Geoffrey Scheurman and Fred W. Newman, "Authentic Intellectual Work in Social Studies: Putting Performance before Pedagogy," *Social Education* 62, no. 1 (January 1998). Authentic intellectual work must meet three criteria: student construction of content knowledge, disciplined inquiry, and real world relevance.
16. UNESCO, 3.
17. M. Gail Jones, *Nanoscale Science: Activities for Grades 6-12*, (Arlington, Va.: National Science Teachers Association, 2007). See also her chapter in the same text focused on ethical issues related to nanotechnology.
18. David Ewing Duncan, "So Long, Lance. Next, 21st-Century Doping," *The New York Times* (January 19, 2013).
19. M. Gail Jones, Bethany Broadwell, Michael Falvo, James Minogue, and Tom Oppewal, "It's a Small World After All: Exploring Nanotechnology in our Clothes," *Science and Children* 43, no. 2 (October 2005), 44-46.
20. Sandler, 21
21. *Nanoethics on the World Wide Web: Helping Faculty Enhance Graduate Education.* Case studies http://depts.washington.edu/ntethics/casestudies/index.shtml
22. Mark Hofer and Kathy Swan, "Digital Docs in a Box," (William and Mary, University of Kentucky, and the Library of Congress, n.d.), http://digitaldocsinabox.org/.
23. Mishra, et al, p. 19

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THE EAST INDIA COMPANY

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Note that without (a) the entity would be a private enterprise and without (b) and (c) this would not be a SOE, but just a public agency like a fire or police department.

5. The Dutch East India Company (Vereenigde Oost-Indische Compagnie, or VOC) was formed (1602) at roughly the same time as the EIC and was also a joint-stock company. The differing fortunes of the British and Dutch efforts are instructive. At the time of the formation of both enterprises, there was a formal stock market in the Netherlands but not in England. Another difference was in the monopoly charters of the two companies. The unregulated EIC sought only to maximize profits for its owners. The VOC charter, in contrast, had a mix of incentives with stockholders benefiting from share appreciation and dividends. Managers, who were also shareowners, were paid based on the company's turnover (sales). The fact that the VOC was more successful than the EIC in the East Indies spice trade in these early decades brings up some subtle aspects in business-government relations. The Dutch government, by steering the VOC toward maximizing sales, was ironically encouraging more competitive behavior; this brings up the enduring question of whether government can steer private business toward a superior outcome. (See Douglas A. Irwin, "Mercantilism as Strategic Trade Policy: The Anglo-Dutch Rivalry for the East India Trade," *Journal of Political Economy* 99 [1991]: 1296–1314).

   It is also interesting to note that although the VOC had more government steering, it operated within a more sophisticated market environment, as evidenced by an active share market and other financial market institutions that did not initially exist in England to aid in the growth of the EIC. Whether a firm has more or less government direction is one variable; the market character of the institutional environment in which a firm operates is also an important determinant of success.
6. Ann M. Carlos and Stephen Nicholas "'Giants of an Earlier Capitalism': The Chartered Trading Companies as Modern Multinationals," *Business History Review* 62 (1988): 398-419.
7. Louis M. Hacker, *The Triumph of American Capitalism* (New York: Columbia University Press, 1940), 163–4.
8. This earlier American fear of lost business activity is similar to what is happening in India today as the Indian government has decided to let Wal-Mart stake out a presence in the country. See, Rama Lakshmi, "Indian Economic Reforms Open the Door to Foreign Retailers," *Washington Post* (September 15, 2012): A6.
9. Anthony Webster, *The Twilight of the East India Company* (Woodbridge, UK: The Boydell Press, 2009).

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