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Author(s): Jones, M. Gail; Blonder, Ron; Kähkönen, Anna-Leena

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1. Challenges in Nanoscience Education

M. Gail Jones (contact)

Alumni Distinguished Graduate Professor

Department of STEM Education

NC State University

Raleigh, NC, USA

Gail_Jones@ncsu.edu

Ron Blonder

Head, Chemistry Group

Department of Science Teaching

Weizmann Institute of Science

Rehovot, 76100, Israel

Ron.blonder@weizmann.ac.il

Anna-Leena Kähkönen

University teacher, LUMA Outreach Coordinator

Department of Teacher Education

University of Jyväskylä

Jyväskylän yliopisto, Finland

anna-leena.m.kahkonen@jyu.fi

Abstract

This chapter examines the challenges that educators face in teaching nanotechnology. A survey was conducted with nano science and engineering researchers and educators from precollege through graduate school to explore issues educators face in teaching about nanotechnology and nanoscale science. The challenges that were noted by survey respondents include a lack of textbooks and instructional materials as well as a lack of laboratory investigations and laboratory equipment. For precollege educators there is a perceived mismatch between the existing science curriculum and the essential concepts that comprise nanotechnology. There is also a need for more professional development to help teachers in precollege, community college and undergraduate levels have the knowledge and skills needed to teach this rapidly evolving area. This chapter highlights the new opportunities that nanotechnology offers for underrepresented minorities to engage in new interdisciplinary areas of science and engineering.

Key Words: nanotechnology education, nanoscience curricula, nanoeducation

1.1 Introduction

Nanoscale science and nanotechnology has grown rapidly and educators are struggling to keep up with the demand for new courses, curricula, textbooks and educational materials. Economic competitiveness has also driven the need for an educated workforce that can push forward advancements in nanoscience and nanotechnology.

The future job opportunities related to nanotechnology span a huge array of fields that include energy, electronics, materials science, auto and aerospace, pharmaceuticals, medical fields, forensics, military and security, sports, and food science (e.g., NNIN 2018). Estimates for the global market value for nano-related technologies vary from \$90 billion by the year

2021 (McWilliams, 2016) to 3 trillion dollars by 2020 (Nanoscale Science and Engineering Education (NSEE)/ NSF 2018). Nanotechnology has influenced all the domains of science resulting in a need for educators at all levels to understand nanoscale science and processes as well as be able to integrate these concepts and skills into new and existing educational programs. This chapter addresses the challenges that educators at the precollege, undergraduate, graduate and informal education levels face as they design and implement nanotechnology education programs.

1.2 Big Ideas of Science and Nanoscience

Educators have begun to identify those cross cutting themes and big ideas that are associated with teaching about nanotechnology (e.g., Jones 2007; Stevens et al. 2009; Sakhnini and Blonder 2015). These big ideas include size and scale, structure of matter, forces and interactions, quantum effects, size-dependent properties, self-assembly, tools and instrumentation, models and simulations, and science, technology and society. Most of these topics are clearly related to existing science domains and are not limited to the study of nanotechnology (Hingant and Albe 2010).

Nanotechnology is typically defined as science and technology that takes place at the nano scale (a billionth of a meter) in at least in one dimension - thus including films, wires, and particles. At this scale-- the world of atoms and molecules-- all the science domains meet and become interdisciplinary. Research evidence has shown that students of all ages struggle with understanding just how small a nanometer is and have even greater challenges understanding how materials behave at this scale (Tretter et al. 2006a; Tretter et al. 2006b).

Previous research has shown that individuals learn about size and scale through experiences such as kinesthetic movement, building things, or by reading and creating maps (Jones and Taylor 2009). But understanding nanoscale is difficult because objects at the

nanoscale are outside of our direct sensory perception. Tretter et al. (2006a) examined the scale concepts of students from elementary, middle, and high school as well as doctoral students and found that students tended to understand relative scale more accurately than absolute scale. Tretter et al. also noted that study participants tended to hold concepts of landmark sizes that included concepts such as the length of a swimming pool or running track. Those scales that fell outside of the experiential world were not held as accurately as those that could be experienced. Tretter et al. (2006b) also examined the accuracy of scale concepts from nanometer to one billion meters for students of different ages and found that there were differences in concepts of small sizes compared to large sizes. Sizes smaller than micro were not well understood at all and students tended to be more accurate at the larger sizes that extended beyond the human scale. Experts (including nano researchers) reported that they just conceptually jumped to the very small or very large scales.

Another challenge for learning about nanoscale science and technology is that materials at the nanoscale often behave very differently than they do at the human scale (Blonder and Sakhnini 2012; Tretter et al. 2006). When working at the nanoscale, counterintuitive properties emerge and challenge our understanding of the behaviors of materials. As an object decreases in size to the nanoscale, intensive properties such as color, conductivity, magnetization, and hardness change - sometimes abruptly. For example, semiconductor quantum dots can change color by altering the size of the particle (Reed, 1993) and magnetic iron particles will completely lose their ability to conserve a net magnetic moment if made very small (Majetich and Jin 1999). To fully understand nanoscale science, students need an understanding of quantum effects (Taylor et al. 2008). Students do not typically study quantum effects until they reach college level science and so precollege teachers face the challenge of how to represent these unique behaviors of materials when teaching about nanoscale science and engineering.

1.3 Nano Education: Precollege to Graduate Education

We conducted a brief survey with educators and researchers to document their perspectives on the challenges and issues related to teaching and learning about nanotechnology. The study began with identifying nanotechnology educators who worked at the precollege, undergraduate and graduate levels. Each of these educators was contacted by email and asked to complete a brief survey that asked the following questions: *What topics (if any) do you teach related to nano education, nanotechnology, or nanoscale science?* 2. *What do you see as the most important challenges for teaching nanotechnology now and in the future?* and, 3. *What should be done to overcome those challenges?*

Twenty-five experienced researchers and educators from seven countries, representing a variety of science fields (i.e., materials science, physics, chemistry, engineering) related with nanoscale science and engineering answered the survey that was sent by e-mail. The respondents were informed about the purpose of the survey and each gave his or her permission for anonymous use of responses. The responses were organized by level (precollege, undergraduate, and graduate) and responses were summarized for patterns.

1.3.1 Precollege Education

The survey respondents who taught at the primary/elementary school level indicated that in most cases nanotechnology is not part of the school curriculum. It is rare for elementary teachers to teach about nanoscale science and technology but there are isolated reports of teachers teaching nanotechnology. For example, in Taiwan nanotechnology was integrated in primary school instruction through nano products (Chen et al. 2012) and in Greece educators have offered a nanotechnology program in primary schools (Manou et al. 2017).

At the middle school level, the survey respondents also noted that nanotechnology is typically not part of the school curriculum and is not typically taught. At the high school level teachers have begun to introduce nanotechnology to students. However, most teachers already face an overloaded curriculum (Gilbert 2006) and adding new topics such as nanotechnology is problematic. Another challenge educators shared in the survey was the need for teaching materials, lab experiments, models (see also Blonder 2010; Ghattas et al. 2012) and on-line animations. This need for materials was connected to the need for didactical knowledge and teaching methods for teaching nanotechnology (Blonder and Sakhnini 2012). Kähkönen, et al. (2011) conducted a survey of Finnish science teachers to assess teachers needs and resources for teaching nanotechnology. This study showed that physics, chemistry, and mathematics teachers thought it was important to teach nanoscience in schools but the lack of resources was a significant barrier to integrating nanoscience into the current curriculum.

For teachers, understanding the knowledge that is behind nanotechnology and nanoscale science is essential in order to introduce nanoeducation in precollege classes. This includes content knowledge of of the fundamental science concepts as well as pedagogical content knowledge (PCK) to help teachers know how to teach nanoscale topics. As mentioned previously, there is a significant overlap of the big ideas in nanoscale science and the traditional themes in science. Part of the solution to integrating nanotechnology may be to help teachers become aware of the areas in syllabi that can be taught utilizing a nanoscale example in addition to, or instead of, a macro scale example. When teaching a cutting-edge research field like nanotechnology, the knowledge is always evolving and teacher professional development is essential for teachers to keep up with the advancements in the field (Blonder 2011). Another factor that was raised by the survey respondents was the need

to teach the interdisciplinary nature of the field of nanotechnology within the subject-oriented science curriculum.

1.3.2 Undergraduate Nano Education

The survey respondents who taught at the undergraduate level indicated that one of the significant challenges is the lack of materials and funding to develop new laboratory investigations. Another challenge was the need to teach about nanotechnology to diverse students who have a variety of majors and backgrounds. A related issue was raised by a survey respondent who noted that the variety of fields that nanoeducation represents makes it a challenge to educate students. Several undergraduate professors noted that being able to understand nano scale and manipulate large and small numbers is an issue when teaching nanoscale science. It was also noted that it is difficult in some undergraduate classes to understand what students come to the class knowing since there is often a general culture where students tend not to talk in class. The complexity of the topic along with the challenge of helping students understand the controversial and uncertain aspects of nanotechnology was also mentioned. One professor wanted students to be able to participate as citizens in public debates around nanotechnology and to contribute to public decisions related to nanoscience and the development of nanotechnology applications.

1.3.3 Graduate Education

Nanotechnology and nanoscale science is most often taught at the graduate levels and is often associated with ongoing research in these areas. Survey respondents noted that the interdisciplinary nature of nanotechnology is a challenge. Students often lack knowledge at the graduate level of other disciplines and the problems that researchers are examining are often messy problems that cross disciplinary boundaries. The rapid development of new tools for researching nanotechnology is also a challenge for educators who must fund access

to equipment to train these young researchers in new techniques. Survey respondents also mentioned that it is challenging to stay up to date in the latest techniques and skills needed to be proficient in this rapidly evolving area of science and engineering. One of the recommendations that was made for addressing the changing fields and advancements is to include more team taught courses, where faculty from different areas can work together to provide students with a rich and relevant experience. As seen in the survey responses from educators at the other levels of education, the lack of materials (textbooks and laboratories) was seen as a challenge to those faculty who are trying to design new courses in nanotechnology and nanoscale science.

1.4 The Interdisciplinary Opportunities Of Nanoscience Education

As noted earlier, science educators who teach precollege science or work with precollege teachers reported that the absence of nanoscale science and technology concepts in the existing school science curricula is a significant problem. Teachers who face a very crowded curriculum are not able to add topics that are not connected to the obligatory science concepts and skills they have to cover (e.g., Pellegrino et al. 2014). Finding connections to concepts and skills that are already taught in school science could scaffold the integration of nanoscale science into the existing science curricula. Stevens, et al. (2009) identified a set of core nanoscale science and engineering ideas related to the curriculum (e.g., forces and interactions) as well as ideas that are unique to nanoscience (e.g., size dependent properties) that could be used by teachers interested in integrating nanotechnology into their instruction. Blonder and Sakhnini (2015) conducted a three-stage Delphi study and invited two communities of experts to participate in the Delphi study: researchers and science teachers. Eight essential concepts of nanoscale science and technology were identified in the study. Another study was conducted to find the insertion points of these eight nano-related essential

concepts with the science curriculum. In this study (Blonder and Sakhnini 2017), experienced chemistry teachers identified the insertion point of each nanoscale science and technology concept to the high school chemistry curriculum. The researchers identified topics in the high-school chemistry curriculum into which the essential nanoscale science and technology concepts can be integrated. Insertion points for all 8 nanoscale science and technology essential concepts were found. In the next stage of the study, insertion points of the nanoscale science and technology essential concepts with the middle-school science and technology curriculum in Israel were studied (Sakhnini and Blonder under review). The teachers who teach middle school science and technology teach the interdisciplinary sciences and technology curriculum, which encourages them to link chemistry, life sciences, physics, and technology subjects. Therefore, those teachers were able to examine different subjects in the curriculum where nanotechnology fits. This emphasizes the importance of nanotechnology's interdisciplinary nature as a suitable platform for teaching science at middle schools. The teachers in the study were able to suggest insertion points for all the nanoscale science and technology concepts in the chemistry parts of the curriculum, whereas in the rest of the curriculum subjects were more challenging for them, especially the physics components. More research should be conducted in order to further clarify the connections between nanoscale science and technology concepts and school science curricula in order to support the integration on nanotechnology into school science.

1.5 Maximizing the Benefits of Laboratory Experiences in Nanoscience

Teachers' extrinsic barriers to utilizing nanoscience laboratories relate to money and time. Money is needed to buy equipment and time is needed for teachers to design and locate instructional activities to include in their science instruction. Notably 49% of high school

teachers in a recent study reported they lacked school resources for nanoscience laboratory work as well as learning materials (Kähkönen, Laherto, & Lindell, 2011).

It is encouraging that the cost of imaging and other equipment that can be used to teach nanotechnology is coming down in cost and some of these tools can be purchased for educational use, such as the AFM (Blonder et al. 2010; Childers & Jones 2015; Jones et al. 2004). Furthermore, common laboratory equipment that can be found in any school laboratory, such as spectrophotometers, can be used to identify nanomaterial based on their color that give a good estimation regarding their size. Educators have also found creative ways to use toys to model how an AFM works with students from middle to university levels (e.g., Planinsic and Kovac 2008, Lindell and Kähkönen 2013).

Should nanotechnology and nanoscale science be taught at the lower levels of precollege education? Both Asian (Chen, et al. 2012) and U.S. (Hutchinson, et al. 2011) studies found that when elementary and middle school students experienced the nanoscale phenomena first hand they were interested in learning more about the topic. Moreover, the recent efforts to create databases and collections of nanoscience learning materials, such as the National Science Foundation NISE Network in the United States, are making it easier to find experimental activities - without expensive equipment or dangerous chemicals.

In higher education, the laboratory work experience is typically either found in a laboratory course or as an experience in a research lab. In research laboratories, Fiore (2008) reported that the presence of researchers from different disciplines changed the laboratory tutoring experience significantly: people used analogies to construct a shared concept base and build a common understanding of how the equipment function and went on to make modifications in set-ups. In contrast, labs where researchers were from the same background resorted to sharing the standard manipulations of a piece of equipment. There's a qualitative

difference between treating the laboratory equipment as just “devices” or viewing learning the equipment as a major skill (Chari 2014).

1.6 Integrating Nanoethical Issues In The Science Curricula

Nanotechnology applications often involve nanoparticles that could provide health or environmental problems (Gardner et al. 2017). As such, the introduction of nanotechnological innovations may be accompanied by significant ethical questions as well as associated concerns about the risks and benefits to humans and the environment (Sandler 2004). Schummer (2007) identified ethical issues of nanotechnologies and noted that discussions of ethical issues are often plagued with “public hype, unclear definition and the early state of nanotechnologies.”(p. 79). Nanotechnology provides an authentic context in which ethical issues can be integrated into science lessons with the goal of educating a scientifically literate future citizenry that can engage in discourse at the intersection of the social and the scientific (Zeidler and Nichols 2009). Educators have been able to design different courses that promote the discussion of nanoethics (e.g., Apotheker, et al. 2017; Powers and Shah 2013). Since many of the nanotechnology applications are still in development and there are still not enough data regarding their risks and possible ethical issues, one strategy has been to use science fiction as a tool to promote the discussion of social and ethical implications of nanotechnology (Berne and Schummer, 2005).

1.7 The Interdisciplinarity of Nanoscience: New Opportunities for Underrepresented Minorities

As the respondents in our survey recognized, some of the challenges related to teaching an interdisciplinary field are very tangible: the students’ background knowledge is unlikely to cover all necessary viewpoints and the available teaching materials do not address the

phenomena in an interdisciplinary manner. One respondent pondered whether it would be realistic to shift courses towards a general, interdisciplinary nano learning environment. This kind of interdisciplinary approach would mean educators would have to change existing courses as well as teaching approaches.

There is some evidence that women may consider interdisciplinary careers as more interesting than work in established disciplines. As nanoscience as a field is relatively new, it may be viewed as a clean slate, without established (unidentifiable) role models. New niches keep opening for new, specialized skill sets. These features offer more routes to positions at the top for underrepresented minorities in science (Rhoten and Pfirman 2007), and it has been shown that female researchers spend more time on interdisciplinary research than males and that they draw from more disciplines (van Rijnsoever and Hessels 2011). If interdisciplinary nanoscience studies and careers can be a part of the solution that addresses the decline in interest in science, this may convince decision-makers of the need for resources to develop new teaching materials and educational programs for the nanosciences.

The interdisciplinary nature of nanotechnology also allows educators and researchers to explore new types of work that require different skills and different ways of investigating science and engineering problems. This collaboration that occurs between disciplines is called interactional expertise (Andersen & Wagenknecht 2013; Tala 2015). The ability to understand and use methods from different disciplines or to integrate seemingly incompatible ideas or standpoints that arise from epistemological differences in the disciplines (Boix-Mansilla 2010) are important skills for nanotechnology researchers. These are skills that differ from those working in one discipline and students with this ability to work in interdisciplinary environments may have a competitive edge working in an emerging area such as nanotechnology.

1.8 Preparing Teachers To teach Nanoscience

A challenge that was highlighted in the survey that hinders the inclusion of nanoeducation programs into precollege science is related to teacher preparation. The scientists who develop nanotechnology knowledge and skills are typically not teachers, and most teachers have not encountered the subject during their studies, since it was not yet widely known when they were students (Blonder 2011, Drane et al. 2009). This situation leads to a need for professional development for teachers that will prepare them for teaching contemporary scientific research in their classes. New professional education courses have emerged in the area of nanotechnology (Blonder 2011, Blonder et al. 2014, Bryan et al. 2012, Gardner and Jones, Gorghiu and Gorghiu 2012, Lin et al. 2015, Tomasik et al. 2009). As noted earlier in the chapter, when it comes to teaching teachers about nanotechnology, the field is constantly evolving. Mechanisms need to be in place to allow teachers to continue to learn about new developments in nanotechnology after the end of a professional development course. One approach to this changing landscape is to help teachers develop a broader type of nano-literacy (Blonder 2011). While this presents a great challenge, it also has numerous advantages. Curriculum developers must consider current learning theories regarding how people learn. Jones et al. (2015) analyzed different kinds of thinking that are required for understanding different nanoscale science and engineering concepts. Children at different ages have different thinking abilities and therefore, different concepts should be taught at different age levels (Jones et al. 2015). Other studies have examined different learning environments for the teaching of specific nanoscale science and technology concepts (Blonder and Sakhnini 2012, 2015).

Nanotechnology offers a unique opportunity for educators to learn new pedagogical approaches to teaching and learning science and engineering. Researchers (Blonder and Mamlok-Naaman 2016) have found that following a professional development course in

nanotechnology, science teachers developed integrated nano instruction for their students similar to the instruction they had experienced in their own course. Moreover, it was found that later on (after 2-3 years) the teachers still applied these teaching methods in their science teaching. The innovative and interdisciplinary nature of nanoscale science and technology may be an ideal platform to promote pedagogical innovation.

1.9 Nanotechnology Education in Museums and Science Centers

Science centers and museums have played significant roles in educating students and the general public about nanoscale science and engineering. These programs have benefited from governmental initiatives to promote educational programs designed to educate the public about advances in nanotechnology (Glass 2007; Roco 2003). Crone (2010) has urged researchers to use museums and informal science centers as a vehicle to reach the public and to garner support for their work. The work of the Nanotechnology Informal Science Education Network (NISE-NET) has proven to be an effective way to gather expertise to design informal education programs that educate the public about emerging issues like nanotechnology (Bell 2008). Since the advancements of nanotechnology impact many areas of our lives, museums and science centers have the potential to play a critical role in engaging adults and youth in learning about new advancements in nanoscale science as well as new applications in nanotechnology.

20. Conclusions

As noted in this chapter nanotechnology offers educators a number of challenges as well as new opportunities to educate the next generation about this important and interesting field. To meet the challenges, educators need additional textbooks and instructional materials to teach about nanoscale science and engineering. It is not yet clear how the precollege

curriculum will need to change to allow teachers to integrate nanoscience into their instruction. One of the challenges that educators at all levels face is a need to help students understand size and scale as well as how materials behave at this very small scale. It is apparent that teachers need professional development on an ongoing basis to keep up with new developments in the field and to learn about new resources and laboratory experiences. The interdisciplinary nature of nanoscience offers educators with an exciting opportunity to engage more students in addressing real world problems with the advancements of nanoscale science and technology.

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