AC 2009-2122: SUPPORTING SECONDARY TEACHERS AS THEY IMPLEMENT NEW SCIENCE AND ENGINEERING CURRICULA: CASE EXAMPLES FROM NANOSCALE SCIENCE AND ENGINEERING EDUCATION

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Supporting Secondary Teachers as they Implement New Science and Engineering Curricula: Case Examples from Nanoscale Science and Engineering Education

Abstract

As is the case for most engineering content, nanoscale science and engineering (NSE) content is often new territory for secondary teachers. Teachers not only have to develop new content knowledge, but they also have to consider how they will teach the new content, where it will fit in the existing curriculum, and what aspects of the new content will be the most interesting and accessible to their students. This paper reports some of the barriers that teachers faced when they implemented new content into their curricula, as well as some of the ways that a professional development (PD) program supported teachers in this challenge. This topic is applicable not only to NSE, but also to K-12 engineering as programs try to support teachers in implementing engineering curricula into their science courses.

Introduction

The National Nanotechnology Initiative defined nanotechnology as “the understanding and control of matter at dimensions between approximately 1 to 100 nanometers, where unique phenomena enable novel applications.”¹ Many special properties occur on the nanoscale, such as optical and magnetic properties that are dependent upon particle size.² The development of nanotechnology comes about through the blending of multiple science and engineering disciplines (e.g., biology, chemistry, physics, materials engineering, chemical engineering, and bioengineering) on the nanometer scale. Because of this convergence, Foley and Hersam argued that the impact of nanoscale science and engineering (NSE) will be broader than any other technological revolution.³ It is predicted that nanotechnology will affect nearly every type of manufactured good over the next ten years, being incorporated into 15% of global manufacturing output totaling $2.6 trillion by 2014.³ It has also been estimated that there will be 2 million jobs created in the areas of NSE by 2015 worldwide, including the creation of 0.8-0.9 million jobs in the United States. In addition to the 2 million NSE jobs, there will be 5 million more jobs created in nanotechnology-related fields. The projected impact of NSE on the economy in the 21ˢᵗ century suggests that there exists an urgent need to educate the future work force of scientists, engineers, and technologists, as well as the general public, about this emerging field.⁴

As a way to educate the future work force in NSE, the National Center for Learning and Teaching in Nanoscale Science and Engineering (NCLT) was created “to develop the next generation of leaders in nanoscale science and engineering teaching and learning, with an emphasis on NSE [nanoscale science and engineering education] capacity building, providing a strong impact on national science, technology, engineering, and mathematics education.” One initiative of the NCLT is a professional development program designed to facilitate 7-12 grade science teachers’ development of NSE content knowledge and integration of NSE concepts into the current secondary science curricula. Teachers who participate in the NCLT’s professional development program were required to integrate at least one NSE lesson during the school year following the summer professional development institute.
Previous research on the integration of innovative science curricula has indicated that curriculum change/reform ultimately hinges on the classroom teacher.\textsuperscript{5,6} Moreover, the process of integrating new content into an existing curriculum is a complex process in which teachers often encounter challenges including: lack of resources (e.g., new science equipment), absence of administrative and peer support, lack of time to plan and teach new lessons, and insufficient content knowledge.\textsuperscript{5,6} Research also has shown that science teachers’ beliefs about teaching and learning as well as their beliefs about the conditions of the classroom and external teaching conditions influence their implementation and integration of new science content and curriculum innovation.

Research Questions

Since 2005, teachers who have participated in the NCLT’s professional development program have been attempting to integrate nanoscience into their existing science curriculum. We (the NCLT PD Team) have observed a range of integration levels – from those who seamlessly integrate nano into their curriculum, to those teachers who do not teach any nano. We also have observed that some teachers take the lessons from the summer institute and adapt them for their classroom; but in the process of their adaptation, eliminate key nanoconcepts from the lesson. Given the variations in how teachers have integrated into their existing curriculum the nanoscience materials from the NCLT’s professional development program, we focused our research on the following questions:

- How do teachers integrate the NCLT’s nanoscience materials into their existing science curriculum?
- What factors influence how teachers integrate nanoscale science and engineering into their curriculum?

Literature Review

Pedagogical Reform Initiatives

Many reform efforts have centered on pedagogical reforms, specifically inquiry-based practices. In examining studies that have focused on inquiry-based practices, several factors that affect the implementation of the reform are apparent. These include: (a) teachers’ beliefs about teaching and learning (the transmission of knowledge, efficiency, rigor, and preparing students for exams), (b) school factors (leadership, class schedules, other concurrent reform initiatives, and supportive network), and (c) teachers’ level of content and pedagogical knowledge.\textsuperscript{6-9} The sections that follow will discuss each of these factors in more detail and explain how each factor influences teachers’ implementation of pedagogical reforms, specifically focusing on inquiry-based practices.

Teachers’ beliefs about teaching and learning have been found to be influential in the implementation of reforms.\textsuperscript{6-9} In a study that investigated the implementation of an inquiry-based chemistry curriculum in a large urban district, it was suggested that teachers’ beliefs about teaching and learning, as well as the presence of a supportive network at the school sites, influenced the amount of implementation.\textsuperscript{6} In this study a mixed-methods approach using 27 teachers was undertaken to examine what factors affected the implementation of a particular pre-
developed reformed chemistry curriculum (*Living By Chemistry*). The protocols used to obtain the data for this study consisted of the Teachers’ Beliefs Interview (TBI), observations using the Reformed Teaching Observation Protocol (RTOP), reflection documents, and school characteristics. These data were analyzed using a constant comparative method. From the data analysis, three groups of teachers emerged: traditional, mechanistic, and inquiry teachers. Traditional teachers did not implement the lessons as desired by the researchers, if they implemented the lessons at all. These teachers held primarily teacher-centered beliefs and modified the inquiry lessons to make them exceedingly teacher-centered. This was evident in the traditional teachers as they focused on teacher-centered tasks such as lectures and worksheets instead of suggested inquiry tasks, including discussions and exploration activities. Mechanistic teachers attempted to stick to the curriculum, but these teachers either utilized inquiry skills that were not very well developed or used teacher-centered beliefs that deterred their implementation of the curriculum. These teachers had limited questioning skills during group activities, employed no cooperative learning strategies, performed activities that were usually completed individually or in informal groups, and failed to wrap-up the lessons with discussions. Furthermore, mechanistic teachers often told students what they should have observed or discovered, or just expected the students to reach the predicted conclusions on their own without guidance. The last type of teachers, inquiry teachers, adhered to the curriculum guidelines and utilized primarily student-centered beliefs. They had strong questioning skills in all types of situations and used cooperative learning strategies. Students drew conclusions from teacher-led discussions following the activities and students often questioned each other and challenged the evidence they were using to make conclusions.

In a related study, Lotter, Harwood, and Bonner used case studies to investigate three teachers’ conceptions and use of inquiry-based instruction. They found that teachers were influenced by their beliefs about teaching and learning. Specifically, teachers were influenced by their beliefs about science, their students, effective teaching practices, and the purpose of education. In this study, the researchers concluded that teachers’ beliefs affected how the teachers translated the inquiry model they were taught during a workshop into classroom practice. If the teachers’ beliefs about effective instructional strategies already aligned with the teachers’ instructional techniques, then there was no need to question the techniques being used and therefore, no change was seen. In contrast, if teachers’ beliefs did not match the instructional strategies, they were more apt to change.

Although not discussed as beliefs in their study, Peers, Diezmann, and Watters, indicated that the teacher’s beliefs about teaching, learning, himself, and his students affected his readiness to implement the reform. This included: how accepting he was to the need for change, his personal interest in the change, how willing he was to explore the reform, his openness to collaborating with others, and his ability to utilize self-reflection.

Roehrig, Kruse, & Kern also discussed the affect of school factors on the teachers’ implementation of an inquiry-based chemistry curriculum. These factors included school-based leadership, school scheduling, and concurrent district reform efforts. They found that the teachers at schools with higher levels of leadership or support were more likely to implement the revised curriculum. As the schools throughout the district observed different schedules and the curriculum being implemented was written for a particular schedule, it was difficult for teachers...
who lacked support to adapt the curriculum to their dissimilar schedules. In addition to this 
reform initiative, some of the schools were undertaking multiple reforms at once. These 
corresponding reforms made it difficult for teachers to find time to include all of the topics 
suggested by the revised curriculum. Teachers also commented that due to time restraints, they 
wanted to drop some sections of the curriculum because it did not match up to the state exam 
students were required to pass at the end of the year.

In addition to the aforementioned factors that influenced curriculum reform, teachers’ beliefs, 
school factors, and content and pedagogical knowledge have also been found to impact both 
teachers’ confidence levels and their ability to teach specific content in an inquiry manner.\textsuperscript{5,11} 
According to Roehrig, Kruse, and Kern, teachers who had limited knowledge in inquiry-based 
methods of teaching often implemented less inquiry-based instruction.\textsuperscript{6} Lotter, Harwood, and 
Bonner also found that content and pedagogical knowledge affected the implementation of 
inquiry methods in their study.\textsuperscript{7} Content knowledge was found to affect teachers’ confidence 
and therefore, deterred teachers from teaching inquiry. Their failure to utilize the more student-
centered inquiry methods was linked to the teachers’ concern that they would not know the 
answers to the lesson before using it in the classroom. These teachers also failed to use inquiry 
because of department-wide exams and coverage of time sensitive topics. Peers, Diezmann, and 
Watters also noted that content knowledge affected the implementation of the inquiry-based 
science curriculum in their study; the teacher had to feel confident in the content before being 
confident in teaching the topic.\textsuperscript{5} In addition to teachers lacking confidence in themselves, some 
teachers also lacked confidence in their own students’ ability to learn through inquiry. In fact, 
these teachers believed that their students learned best through the transmittance of facts. In a 
successful case that demonstrated the implementation of inquiry within the classroom, the 
researchers noted that the teacher had a strong content background, which allowed him to push 
his students more into a student-led classroom.\textsuperscript{7} This suggests that content knowledge 
contributes strongly to the implementation of reform efforts, even if the reform effort is 
pedagogical. This assertion has been supported by the work of Toolin, who examined teachers’ 
implementation of project-based learning (PBL) in middle- and high-schools.\textsuperscript{9} In this study, the 
researchers found that the type of degree obtained, the number of years teaching, and the number of 
PBL workshops attended affected the teachers’ levels of implementation. Specifically, the 
teachers that had more expertise in the area of PBL, had more advanced degrees (MS in 
education), were more experienced, and had attended workshops on PBL were able to implement 
PBL into their classrooms, whereas teachers that lacked advanced degrees and had limited 
experience did not implement PBL into their classrooms.\textsuperscript{9}

This section has summarized how teachers’ beliefs about teaching and learning, school factors, 
and teachers’ content and pedagogical all influence the implementation of a pedagogical reform. 
The next section will continue discussing factors that affect the implementation of reform efforts; 
however, the focus will be on content-specific reform initiatives.

\textit{Content-based Reform Initiatives}

Content-based reform initiatives have also occurred, however, there are few studies on these 
initiatives, and many times even if new content (or new course) is introduced and studied, the 
focus is more pedagogical. Content reform initiatives have explicitly examined the
implementation of specific material into the curricula. In this section, I will discuss a few studies that have explored this implementation, including the efforts of reform regarding technology and revised science content.

Barnes investigated the factors that facilitated teachers’ implementation of a technology curriculum, where the teachers were voluntarily implementing a new technology curriculum. The investigator found that factors of student interest, external curriculum, supportive school environment, personal renewal, and leadership style influenced the teachers’ decision to implement the new technology curriculum. Teachers commented that students were becoming uninterested in the old curriculum; therefore, they wanted to change this stagnant curriculum to increase student interest and in turn, hoped to improve student achievement. The teachers also recognized that their curriculum was outdated by recognizing that other areas of the world were implementing novel technology curricula. These cutting edge developmental changes encouraged them to redesign their course materials. The support from their school system also influenced their ability to incorporate a revised curriculum. The researchers found that the more positive the support was from the schools, the more successful teachers were in their implementation. Specifically, a group of teachers in this study found it difficult to make changes to their curriculum at other schools due to a lack of support. Internal factors also influenced the teachers’ implementation ability. This was observed in the form of personal renewal or reflection brought on by career dissatisfaction. As teachers were not satisfied with how they were teaching their students, they reflected on the issue and found a way to change what was dissatisfying them through the modified curriculum. Finally, two different types of leadership were found in teachers that implemented the new curriculum. One form of leadership indicated that the individual was willing to implement new ideas when no one else was, while the other leadership type would support his or her peers in the implementation of a modified curriculum.

Outside of technology, content reform has also been explored specifically within the realm of science. In a study that examined the school factors that influenced the introduction of a new science curriculum into schools, Owen found that science teachers had to be open to using new curriculum materials and willing to work together with other teachers in planning lessons and units. Although the researcher indicated that these components were necessary for the success of implementing the new science content, they were not necessarily sufficient. It was also apparent that the head of the science department influenced the successful implementation of this content.

Very few studies have investigated explicitly content-based reform; rather the studies focus more on pedagogical reform efforts. Researchers often discuss new curricula, however, this curricula is the same content, using different pedagogical techniques, most often inquiry and problem-solving skills.

**Characteristics that Influence Reform Efforts**

Many researchers have investigated factors that influence reform which have been discussed in the previous sections as influencing both pedagogical and content-based reform efforts of the curriculum. Teachers’ beliefs about teaching and learning have been found to strongly influence both pedagogical and content-specific reforms. If a teacher’s beliefs align with the reform
efforts, they will be more willing to accept the reform as they can see benefit in the reform. If a teacher’s beliefs do not align with the reform efforts, it is more difficult for these teachers to adapt the new curriculum (reform) for their classroom. Because of their beliefs, they will not be able to see the benefit of the reform for their students.

Various school factors also affect the implementation of new reforms into schools. These factors include school scheduling, school-based leadership, and concurrent reforms. Some curricula are developed for a particular school schedule (traditional 40-50 minute classes) and it is difficult for teachers to adapt the curricula for their school schedule (block scheduling) when it differs. Teachers are often more able to implement lessons into their classrooms when leadership is present to facilitate the implementation of new curriculum as these leaders can assist in adapting the curriculum for their particular school and needs. Concurrent reforms at a school can often influence the reform under investigation as teachers are attempting to balance a variety of new tasks in their classrooms. When there are concurrent reforms, teachers’ beliefs about teaching and learning often affect which reform or which aspects of various reforms teachers choose to implement.

Teachers often state that the presence of a supportive network both at their school and from professional development staff positively influences their implementation level. This positive influence may be because the teachers have other individuals whom they can ask questions of and develop a better understanding of the reform and of how to implement the reform. Unless a teacher is motivated or their beliefs about teaching and learning align well to the reform, the lack of a supportive network can be detrimental to the continuation of the reform efforts as teachers will have difficulty implementing the reform.

Strong content knowledge and pedagogical knowledge positively influence teachers in implementing a reform. The more confident teachers are in the subject-area (content), the more apt they are to attempt new methods and topics within the subject-area. If teachers are already having difficulty in the content area for which they are teaching, they are less likely to implement a new reform, whether it is content-specific or pedagogical.

The characteristics that influence reform efforts have implications for professional development programs. The effects of professional development on science reform will be discussed in the next section, in which many similar characteristics may be seen.

Effects of Professional Development on Science Reform

Fullan argued: “You cannot improve student learning for all or most students without improving teacher learning for all or most teachers.” This statement indicates that teacher and student learning are intertwined. Often, reform efforts have been unsuccessful because they do not take into account teachers’ prior knowledge and beliefs. As a result, the success of reform efforts tend to be determined by teachers; therefore, if reforms are to occur, successful professional development programs are necessary. These programs will help to improve teacher learning, which will in turn enhance student learning.
In recent years, there has been an increase in the quantity of literature devoted to describing what a successful professional development program should look like. Most researchers agree on specific criteria that will make a professional development program successful. The key features of a successful science professional development program include: (a) intensive and sustained training with opportunities for active learning, where teachers are able to practice using the skills and knowledge developed, (b) delving into deep science content and process knowledge (subject-matter knowledge), (c) modeling strategies teachers will use with students, (d) considering teachers’ beliefs, and (e) considering other reforms occurring at the school and coherence with other learning activities. Each of these effective professional development factors will be discussed in more detail in the following sections.

The duration of a professional development program is related to teacher change. Researchers have found that the longer and more sustained the contact, ideally lasting for several years, the larger the impact on teachers’ knowledge, skills, and beliefs. Garet, Porter, Desimone, Birman, and Yoon, in a national study that was based on teachers’ self-reports, found that sustained and intensive professional development was more likely to have an impact than shorter programs. This is likely due to the fact that there are more opportunities for content and pedagogical discussions of students’ conceptions during longer programs with sustained contact. During such extended time, there is also time for teachers to implement their new practices and receive feedback. In a study by Supovitz and Turner, which examined the relationship between professional development and reform developers’ vision of the reform, the researchers found that the amount of professional development teachers participated in was strongly linked to their teaching practices and classroom cultures. They found that the more intensive and sustained the professional development, the more teaching practices and classroom culture were affected, including matching the expectations of the reform developers.

Part of sustained contact in a professional development program can include follow-up meetings, observations in the classroom, feedback on lesson implementation, and general communication throughout the year. In a study that examined the effects of a professional development program on teachers’ inquiry practices and beliefs, “participants expressed the need for additional follow-up opportunities that included planning and critiquing lessons, exploring various aspects of science related investigations, and discussing inquiry instruction with administrators”. The same teachers also expressed the value of being observed by a professional development staff member who, following the observation, would discuss the implementation and provide feedback. Teachers believed that this feedback helped them in furthering their implementation of the lessons. Teachers were also given the opportunity to observe their peers as they taught a lesson, which was useful in collecting ideas from their peers’ lesson plans and in determining some of the issues that may arise when implementing the lesson. Teachers being observed by staff members and peers are both examples of sustained contact that assisted teachers in furthering their knowledge and skills in the enactment of science reform efforts. The preceding studies indicate the benefits of a long duration and sustained contact professional development program: the longer teachers are able to interact with the content and instructions of the program, the more apt they are to adapt to the reform.

Because teachers’ content preparation has a strong influence on their teaching practices and also improves students’ conceptual understanding, professional development should focus on
developing teachers’ content knowledge, the ways students’ learn that content knowledge, and skills. For instance, Jeanpierre and coworkers have demonstrated that teachers with weak content knowledge tend to utilize teacher-centered practices due to their lack of confidence in the subject-matter rather than student-centered practices. Kennedy determined that “programs that focus on subject matter knowledge and on student learning of particular subject matter are likely to have larger positive effects on student learning that are programs that focus on teaching behaviors.” This statement echoes research by Cohen and Hill that determined that student achievement was higher for teachers that participated in a professional development focused on content rather than a professional development program focused on pedagogy. Birman et al. also noted that teachers’ reported increases in their knowledge and skills when professional development focused mostly on content knowledge. These studies all indicate that teachers must be immersed in the subjects they teach. This immersion will assist teachers in developing the confidence to teach the subject-matter and improve students’ conceptual understandings.

In a professional development experience, teachers should have opportunities to engage in lessons that are consistently presented as they should be conducted in the classroom, discussions of the lessons, curriculum and pedagogy, planning of lessons for the classroom, and practice in teaching new lessons. Furthermore, having multiple experiences facilitates teacher learning. Professional development instructors should teach the lessons in the same manner as they would like teachers to teach the lessons to their students since this allows teachers to observe expert teaching. As stated by Loucks-Horsley et al. science and mathematics teachers “need to experience for themselves the science and mathematics learning they will want their students to do. Hearing about it in a vicarious manner is no substitute” because it is “difficult if not impossible to teach in ways in which one has not learned”. These researchers also highlighted the importance of teachers planning how they will use the new materials they have been taught in their classrooms. Additionally, Luft connected teachers’ planning and discussion time to the development of teachers’ beliefs and practices. The previous studies have indicated that discussions of the lessons and pedagogy and having time to plan the lessons have assisted teachers in implementing the lessons into their classrooms. Researchers have also indicated that teachers have been influenced the most by engaging the lessons from a student perspective. This engagement in lessons allows teachers to see how the lesson should be taught in the classroom and allows them to examine not only the teacher experiences, but also the student experiences associated with the lesson.

Although the previous studies have indicated that teacher experiences are highly significant, teachers’ beliefs also need to be considered in any professional development experience as their beliefs are very strongly intertwined with their teaching practices. In fact, much research has shown that teachers’ beliefs strongly influence their classroom practice. Nespor emphasized the importance of teacher beliefs when she stated, “the contexts and environments within which teachers work, and many of the problems they encounter, are ill-defined and deeply entangled, and that beliefs are peculiarly suited for making sense of such contexts”. Luft, who examined changes in teachers’ beliefs and practices as a result of an in-service professional development experience, found that teachers made significant changes in their inquiry practices, while their beliefs did not change. After further investigation, Luft found that novice teachers with only minimal teaching experience changed their beliefs more than their practices, whereas
experienced teachers had larger changes in their practices than their beliefs. These changes may have been due to how deeply-rooted each participant’s beliefs were and how their beliefs matched the inquiry practices of the professional development program. Because of their beliefs, teachers have been shown to incorporate bits and pieces of the material and practices taught in a professional development program, but do not completely change their teaching practices. Richardson also noted that professional development needs to consider teachers’ beliefs if there is going to be a change in teachers’ practices, because if beliefs are not considered, only teachers with beliefs consistent with the practices will change. Therefore, when developing a professional development program, teachers’ beliefs need to be considered if teachers are to make any changes to their practice and curriculum. If teachers do not believe that the content or practices used during the professional development program will be useful for their students and will help their students learn, they will not incorporate the materials and practices.

The reform efforts of a professional development program need to also consider the school environment and other aspects of school reform that may run concurrent with the professional development program. Garet et al. suggested that when the professional development program is coupled with teachers’ other experiences and is aligned with other reform efforts, a change in teaching practice occurs. In examining school factors that affect reform efforts, Supovitz and Turner found that a school’s socioeconomic status (SES) was more influential to changes in practice than support from the principal or the availability of resources. The researchers found that teachers from low SES schools used more teacher-centered and traditional practices compared to teachers from high SES schools. This does not mean that teachers at low SES schools cannot change their teaching practices, but it does indicate that curriculum developers must consider the teachers, students, and school culture that will be associated with redesigned curriculum.

In conclusion, professional development programs that: (a) are of longer duration, (b) focus on subject-matter (rather than pedagogy), (c) model the desired practice, (d) consider teachers’ beliefs, and (e) consider the school environment and other reform efforts occurring at the school, positively affect teacher learning.

These aspects of professional development that have been found to positively influence teachers were all considered in the development of the professional development program for this study. The program is of long duration in that the teachers attend a two-week summer institute, attend a spring follow-up seminar, and are in contact with the professional development staff throughout the school years following the program. The focus of the program is nanoscale science and engineering therefore making it content focused. During the two-week summer institute, teachers are engaged in the lessons as their students would engage in the lessons. Teachers are also involved in discussions of why the lesson was designed in the manner it was and where they could fit it into their curriculum. It is hoped that by using these aspects of effective professional development, the professional development program on NSE will be positively influenced.

**NSE and the Secondary Classroom**

According to the National Nanotechnology Initiative, nanotechnology is defined as “the understanding and control of matter at dimensions at approximately 1 to 100 nanometers, where
unique phenomena enable novel applications. Encompassing nanoscale science, engineering and technology, nanotechnology involves imaging, measuring, modeling, and manipulating matter at this length scale”. The National Science Foundation (NSF) called one nanometer a magical point on the dimensional scale and discussed the novel properties that occur on the nanoscale, such as optical and magnetic properties. Nanoscale science and engineering (NSE) takes advantage of the novel properties and phenomena that occur on the nanoscale level as these properties are very different than the bulk materials. As NSE explores systems that range from 1 to 100 nanometers, a variety of disciplines have combined their efforts to investigate nanoscale systems, which has resulted in interdisciplinary studies between chemists, physicists, biologists, technologists, and engineers. Together, they are improving our understanding of the size-dependent properties and the dominance of intermolecular forces that exist on the nanoscale. Utilizing this enhanced understanding has led to the development of new tools and instrumentation. The benefits of applications of nanotechnology are widespread influencing technology, medical diagnosis and treatment, environmental issues, and everyday products.

Educating students about nanotechnology in secondary science is essential for the future of the United States and the world. Reasons include the movement of the science and engineering workforce needs, financial investments in new products and applications utilizing nanotechnology, public policy issues related to nanotechnology, and calls to reform the current structure and content of secondary science education. The following sections include a discussion of these reasons supported by the current literature available related to nanotechnology and nanotechnology education.

Nanotechnology incorporates aspects of biology, chemistry, physics, engineering, and technology, making it an interdisciplinary field, and therefore affecting jobs in all of these fields. NSE is expected to have a large impact on all of the economy in the 21st century, therefore creating an urgent need to educate the future workforce of scientists and engineers as well as the general public about this emerging field. In a Web of Science database search by Foley and Hersam using the keyword “nano*”, they found the yearly production of nanotechnology publications worldwide “increased approximately 8-fold in the past ten years, and more than doubled between 2000 and 2004”. Looking towards the next 20+ years, the technical advisory group for the President’s Council of Advisors on Science and Technology identified areas which will be impacted by NSE. They believe that in 1-5 years, improvements will be made on nanocomposites, chemical and biological sensors, batteries, and diagnostic devices, while in 5-10 years, there will be drug therapies designed to target particular places in the body, improved medical imaging, and an efficient manner to convert water to hydrogen. In the long term (20+ years) NSE may be developed enough to have drugs delivered through cell walls, molecular electronics, and neural prosthetics. These predictions of future technologies that rely on fundamental knowledge of nanoscale concepts emphasize the importance of having a skilled and knowledgeable future workforce. We can begin to prepare the pool from which we will recruit this workforce by educating students about nanoscale concepts in their secondary education experiences.

Public and private investments have been and continue to be made in nanotechnology. Since the commencement of the NNI in 2001, federal funding for NSE research and development has increased significantly from $464 million to approximately $1.081 billion in 2005. This vast
interest in nanoscience can also be seen with global government funding which has increased eight fold from 1997 to 2005 to more than $4 billion annually. When taking into account all public and private sectors, the investment in NSE is estimated at $9 billion annually.³ This investment in nanotechnology will provide those educated in nanoscale concepts secure career opportunities.

As NSE is rapidly growing, it is imperative that the public has an awareness of NSE. The current literature suggests that there is room for growth in the area of NSE public awareness. In a mixed-methods survey, Bainbridge found that members of the general public who already held an interest in science, were also interested in nanotechnology and had an understanding of some potential benefits.³⁰ Since that time, the topic of nanotechnology has increasingly been capturing the public’s interest through the use of media. Although the public is becoming more aware of NSE through media, such as television, books, magazines, movies, and the Internet, a survey of 495 people ages 7-91 by Castellini, Walejko, Holladay, Theim, Zenner, and Crone indicated that only 42% had heard of nanotechnology and from that population, only 41% could correctly define nanotechnology.³¹ The public also lacks an understanding of the concepts associated with the size of the nanoscale and atoms with only 7% of the participants correctly ordering microscopic objects. The above study also examined public attitudes which indicated overall neutral attitudes toward nanotechnology and its impact on society, but indicated they believe nanotechnology is somewhat important, safe, and beneficial.³¹

The public needs to be informed about NSE for several reasons. Already NSE is in the media with many people giving their interpretations of research. It would be helpful if the public was educated about nanoscale phenomena and nanotechnology so they would be able to interpret statements of the media and make their own educated decision about NSE. Policy-related issues will also arise because of NSE. The public will then have to vote on these issues related to nanotechnology therefore they should have a basic understanding of NSE. Currently, ‘nano’ is used as a ‘buzz word’ for many items which consumers buy, however, if the term ‘nano’ begins to have negative meaning for consumers, the public may not support nanotechnology-related policy decisions. There are many products that sell using the term ‘nano’, such as paint, waxes, sunscreens, and band-aids so it would be it would be beneficial for the public to know more about these products, especially the related safety issues.

There are other reasons the NSE concepts can benefit secondary curricula. Literature indicates a need for the overhaul of the United States science curricula due to the national (NAEP) and international (TIMSS) test scores being deemed low and uncompetitive.³ While incorporating nanoscale concepts into secondary curricula is not a large overhaul, it does begin to change some of the foundational aspects of science education. As NSE focuses on the science and engineering of atoms and molecules, it brings an emphasis to molecular-level science, which was a strong suggestion for change in science curricula made by Robert Tinker and Qin Xie of the NSF-supported Concord Consortium.³² Lederman and Bardeen’s work also supported this statement when indicating that atoms and molecules should encompass biology, chemistry, and physics education, as atoms and molecules comprise 100% of chemistry, 90% of molecular biology, and 85% of physics.³³
Another suggestion for improving 7-12 science courses is integrated science courses as an improved practice, which allow students to explore cross-disciplinary concepts. Integrated science courses unify concepts, therefore presenting a more real-world view of science in contrast to traditional science courses. The science can then be more relevant to students’ lives, potentially increasing their interest and motivation to learn. Because changing the 7-12 education system to rupture the typical divisions of science and become fully integrated will be an enormous undertaking, NSE is one avenue to consider implementing in the classroom as a starting point. NSE can be used as a starting point as chemistry, biology, physics, technology, and engineering are all components of nanotechnology making it an interdisciplinary field and provide opportunities to create interconnected knowledge and coherence in middle- and high-school classrooms.

Student interest in science and engineering may also be positively influenced with the integration of nanoscale concepts, if integrated by linking to the present, real-world context. Research has suggested that students are more motivated to learn and their achievement levels increase when teachers use practices and topics that stimulate student interest. Student interest is often sparked from topics that are relevant to their lives and novel, such as pharmacology topics. Through NSE, many modern applications and products have been produced, such as stain-resistant clothing and paint, which can influence the teachings in traditional class settings. These modern products may be of interest to students as they are real-world applications with personal relevance. Traditionally taught topics can also be taught using NSE. For example, the concept of a gecko walking on the ceiling can teach intermolecular forces. This type of real-world concept may have the potential to increase student interest, and has the potential to increase student learning. Due to the integrated, novel nature of NSE and its increasingly greater impact on society and the real-world, this may be one approach to increase students’ interests and motivation in science, and in turn, increase their achievement levels and will to explore and learn science.

A variety of reasons to incorporate nanotechnology into the secondary science curriculum, including future workforce needs, economic investments, public awareness, and improvements to the structure of secondary science curricula. The collection of these reasons makes a strong case to continue to work with secondary teachers in their ability to facilitate student learning of these foundational nanoscale concepts.

**Teachers’ Implementation of NSE**

Recently, there have been professional development programs in nanoscience for secondary teachers. For one particular program, teachers were taught nanoscience concepts through lessons as if they were the students, attended seminars by nanoresearchers, experienced a state-of-the-art cleanroom, and concluded the program with the creation of a nano-lesson to be used in their classroom. Daly, Hutchinson, and Bryan found that middle- and high-school teachers created lessons on science concepts already taught in their classrooms, such as size and scale and intermolecular forces, rather than concepts considered more central to nano, such as self-assembly. This indicated to the researchers that the teachers may have found it difficult to incorporate the nanoscale topics into their current classrooms as they did not know where to fit nano into the curriculum, even though they indicated in an interest in NSE and the NSE lessons...
they were taught. Teachers often created lesson plans on traditionally taught topics and added in nano-extensions to their pre-existing lessons, rather than making nano an integral part of the lesson. They found it easier to improve lesson plans on topics they already taught rather than adding in new topics. These teachers also did not demonstrate the interdisciplinary nature of nanoscience when creating their lesson plans. The authors indicated to the teachers that nanoscience should not be taught as a solitary unit, but rather be integrated in throughout the year. They suggested this could be done by integrating nanoscience concepts into current teacher lesson plans. Although these authors indicated to teachers where nano may fit in the curriculum, teachers found it difficult to integrate into the curricula.

Previous research on the implementation of innovative science curricula has indicated that there are barriers that teachers face in integrating new content. These barriers include a lack of science equipment, lack of support from a professional development team, lack of time to plan and teach the lessons, teacher content knowledge, and teachers’ beliefs about the teaching and learning as well as the innovation to be implemented. One innovative science curriculum currently under investigation is the topic of nanoscale science and engineering (NSE). NSE is important due to its emerging prominence in society. Because of this emergence and the effects it will have on the job market and society, NSE needs to be taught to K-12 students. As this new curriculum is implemented into classrooms, many barriers to implementation may arise. This pilot study specifically examined the content barriers uncovered during the second year of an NSE professional development program. Results indicated that teachers decided which NSE lessons to implement based upon how they believed the lesson would fit into their pre-existing curricula and their level of content knowledge on the topic.

Methods

The professional development program consisted of an intense two-week summer institute as well as year-long follow-up. This program is designed to provide 7-12 grade science teachers with enhanced NSE content knowledge, to provide teachers with NSE lessons and assist them in developing an NSE lesson they can teach in their classrooms, and to make teachers more aware of the interdisciplinary nature of NSE. Within the two-week summer institute, participants were exposed to NSE content by performing NSE lessons that can be taught in their classrooms, seminars from practicing NSE researchers, and NSE experiences such as lithography in a cleanroom.

Throughout the two-week summer institute, data were collected in the forms of lesson feedback forms, written responses to lesson assignments, the creation of lesson plans by the teachers for use in their own classrooms, and a focus group that occurred at a follow-up weekend meeting.

Participants

This study examined twelve participants from the 2007 summer professional development institute. The table below gives a description of the teachers that submitted their lesson plans in 2007, with the first letter indicating male or female and the second letter indicating middle or high school. The names following are pseudonyms for the participants which will be used later.
Data Collection

Data for this study consisted of teacher lesson plans, a focus group with all participants following the implementation of their lessons, and one interview with a participant about her experience during the implementation of NSE lessons.

During the two-week summer institute, teachers developed an NSE lesson plan that involved modifying an existing lesson from the two-week institute. Teachers were asked to neither modify nor create a lesson on size and scale because the professional development team did not believe this lesson directly addressed a nano-phenomenon and we wanted teachers to select a lesson that addressed a nano-phenomenon, such as nano-magnetism or quantum dots. Teachers were given support from the professional development staff during the second week of the institute as they developed their NSE lessons.

A focus group was performed during a follow-up weekend program to allow teachers to express why they chose the lesson they did to implement, to express how successful they believed the lesson was, and to explore what affected the implementation of the lesson. The following questions were asked in the focus group by members of the professional development team:

1. How did you choose the lesson you chose to implement?
2. What issues, if any, did you have to consider before implementing the lesson?
3. What issues, if any, arose while implementing the lesson?
4. What facilitated the integration of the lesson?
5. What hindered the integration of the lesson?
6. How would you change the lesson now that you’ve taught the lesson at least once? Why?
7. What advice would you give to another teacher who wants to implement a nanoscale science and engineering-lesson?
8. How do you see nanoscale science and engineering fitting into your curriculum?

As a way to gain insights into one teacher’s implementation process, we interviewed one participant in a semi-structured manner following her implementation of several NSE lessons in the classroom. The interview was conducted in two parts, one immediately following the lesson and another after the collection and assessment of student artifacts; both were approximately 45 minutes in length. These interviews were guided by the following questions:

1. Why did you choose to teach this lesson?
2. What outcomes did you hope to realize when you chose to teach this lesson?
3. How prepared did you feel to teach these concepts to students?
4. How did the NCLT’s PD workshop contribute to your feelings of preparedness?
5. What helped you to integrate [topic] into the classroom?
6. What hindered you in integrating [topic] into the classroom?
7. How did the collaborations with the NCLT’s members contribute to your feelings of preparedness?
8. As you developed your lesson plan after the PD workshop, what specific aspects of the workshop helped you most?

Data Analysis

The data were analyzed using a constant comparative method of analysis.40 We examined the lesson plans to determine which topics teachers selected to teach in their classroom. Following analysis of the lesson plans, we reviewed the transcripts from the focus group and interviews to determine why those lessons were selected and how the implementation of those lessons occurred. We then looked at individual responses and identified trends among all of the teachers.

Findings

Lessons chosen by teachers to integrate

The data indicated that the nano-related content teachers choose to integrate into their curriculum was influenced by their level of confidence in the content as well as how well they believed the nano-content fit their pre-existing curricula. Table 2 indicates the lessons teachers utilized at the conclusion of the summer institute. Teachers most often chose to use lessons that were already a part of their pre-existing curricula. Although teachers were asked to not create or modify a size and scale lesson, one teacher still chose size and scale.

Table 2. 2007 Participants’ selection of nano lesson plan

<table>
<thead>
<tr>
<th></th>
<th>Size and Scale</th>
<th>Intermolecular Forces</th>
<th>Microscopes</th>
<th>Magnetism/ Ferrofluids</th>
<th>Models</th>
<th>Nano &amp; Society</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jason</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>John</td>
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<tr>
<td>James</td>
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<tr>
<td>Amber</td>
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<td>X</td>
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<tr>
<td>Mark</td>
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<tr>
<td>Brenda</td>
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<tr>
<td>Craig</td>
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<tr>
<td>Keith</td>
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<td>Kevin</td>
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<td>Mitch</td>
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<td>Drew</td>
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<td>Jeff</td>
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<td>2</td>
<td>2</td>
<td>1</td>
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</tbody>
</table>
The lesson on intermolecular forces was implemented by the largest percentage of teachers. Intermolecular forces may have been chosen as the lesson to implement most often by the high-school chemistry teachers because this was a topic that was already in their current curriculum. This lesson was an adaptation of a lesson that several of the participating teachers already taught, so they felt that it was easy to integrate nanoscale aspects. A trend that cannot be seen by examining the table is that teachers chose not to focus on highly nano-related lessons. These lessons included allotropes of carbon, self-assembly, and quantum dots (which we taught for three days during the two-week workshop). Although teachers indicated that they enjoyed these lessons, they chose not to create lessons on these topics for their classrooms. The teachers expounded on the reasons for not using the highly nano-related lessons in the focus group and teacher interviews.

Factors influencing lesson choice

Five factors emerged as being most influential in teachers’ decision to integrate nanoscience lessons into their existing curricula. These factors included: relevance, student motivation, inflexibility of existing curriculum, technical considerations, and content knowledge.

Teachers most often stated that they selected lessons based upon relevance or fit to their pre-existing curriculum and to their state’s standards. Some teachers discussed relevance by indicating that they had to select lessons that would better prepare their students for taking graduation exams, and the lessons that they could conceptualize that would help their students were topics they already directly discussed in their current classrooms, such as intermolecular forces:

I think one of the things was relevance to the curriculum I was currently teaching, kind of matching up some of the concepts we’re hitting in the nano-lessons with current curriculum, or in another class I was currently teaching. That was probably one of the first things I looked at was relevance. [John, high school]

I saw this as something that could tie right in with something I was doing already and could be better, an improvement on what I was doing. [Craig, middle school]

Teachers also determined the topic to select based upon what they believed was foundational knowledge their students should know, such as size and scale. Teachers often chose the lesson they created based upon the content that they believed to be the most easily integrated into the classroom.

I would say in addition to relevance, working at the junior high level, that it was I tried to pick the ones that were more foundational as an introduction to, as well as an addition to, what I was going to be teaching be foundational to the concept of nanotech or nanoscience that could kinda lead them toward a better understanding — or just what is it, what it’s about, and how it’s connected to other things we’re already doing. [Keith, middle school]
In choosing a lesson, some teachers considered motivational factors for their students. They indicated that they teach science to students who are not interested in many science topics, and therefore wanted to select lessons they thought would engage and interest their students. For example, Amber stated that she wanted to do the microscopy lesson because “that is cutting edge right now and it will help to get students interested in the field” (Amber, Interview 1, August 2007). She often talked during the interview about how she wanted students to be interested in the lesson, and she believed that they were interested due to the amount of engagement during the class periods by the students.

Depending on the school district, some teachers had very little leeway in developing new lessons for the curriculum. This was because in some schools, the teachers had to be teaching the same topic in the same manner on the same day. Their entire school year was determined by the district, school, and/or department. Therefore, teachers felt that they had little say in changing the curriculum. As a result, these teachers choose nanoscience lessons closely related to what other teachers were already teaching, such as size and scale and intermolecular forces. For example, Brenda stated:

Our particular county has decided to do something called “curriculum mapping” which pretty much says that all of us teaching this, have to teach it with this, at this time, on the same dates, so that it’s very rigid. [Brenda, high school]

Additionally, teachers also had to consider technical aspects of integrating nanoscience lessons. For instance, they had to take into consideration the time required to set-up the lesson and conduct the lesson, as well as the equipment and technology needed for the lesson. In considering the amount of time, teachers stated that they had to decide which existing lessons they would cut in order to add in new lessons. One teacher commented that he needed to decide if he would “get more bang for his buck” if he inserted a nano-lesson and removed another lesson from his curriculum.

When teachers discussed the implementation of their lessons, they often noted that their content knowledge was an issue. This trend was found among teachers who chose to implement more nano-related lessons (such as ferrofluids) as well as teachers who implemented lessons on topics with which they believed that they were very familiar, (e.g., intermolecular forces). Teachers did not always feel they had an adequate understanding of the topic they were trying to integrate into their curriculum. Several teachers noted that if they had a scripted lesson from which they did not stray, they would be fine in teaching the lesson:

With the ferrofluids, I came up against – being removed from physics for a long time, all the magnetism issues and the misconceptions kids bring in about magnets and magnetic fields – they helped me though a lot of that. But it was kind of all of a sudden, they don’t get this. They’re coming to this from a totally wrong perspective. How am I going to deal with this issue? [Kevin, high school]

I see one of the valuable parts of introducing that kind of lesson is if that level is raising questions, but at the same time, dangerous part of raising questions with something
completely new and also trying to provide the right foundation that doesn’t leave them with a lot more misconceptions after they’re done. [Keith, middle school]

These teachers also noted that when their students started asking questions, they felt that they did not have the content knowledge required to answer the students’ questions. Many of the teachers also commented that they would teach more of the “nano-lessons,” such as self-assembly and quantum dots, if they had stronger content knowledge of these topics.

As Amber explained above, she felt as if she needed to know more content to be able to effectively teach nano in the classroom and to feel more comfortable in integrating more nano into their classrooms. Amber also indicated that although doing the lessons in the summer institute helped her to feel more confident in performing the lessons in her classroom; she did not believe that she would have been able to do the lessons without the assistance of a professional development staff member in the classroom with her. The teacher indicated that “I felt very inadequate because it was the first time doing it. It’s always scary doing a lab for the first time.” In this instance, the assistance of a staff member made her feel more confident because she could talk over the concepts before doing the lesson. During the lesson, it was helpful since there was someone else in the room that would be able to answer student questions or catch any problems that may have arisen. The teacher also discussed how she was “overwhelmed at the prospect of having to make the equipment and supplies” because it takes a lot of time, so having one of the NCLT’s staff members bring equipment and supplies assisted in limiting the amount of preparation time.

The teacher also indicated how the NCLT’s summer institute affected her implementation levels of nano. She discussed how talking with teachers about the pitfalls of the lab, how to speed parts up, how teachers will respond, what will they get, and what they will not get helped in developing a lesson for her specific classroom. This teacher also discussed that having the lessons already written out and the worksheets already done helped in doing the lesson. She only had to make minor adjustments to a lesson rather than creating a new lesson which saved time.

Conclusions

The data indicate that there are several factors that affect teacher implementation of lessons, but that teachers also believe that there are ways to implement nano into the current science curricula. Teachers discussed that relevance and fit to their curriculum was important in which lesson they chose to develop during the summer institute. They had to consider other faculty in the school, state standards, and graduation exams when developing their lesson. Teachers also considered time, equipment, and technology when implementing lessons. If they were going to add in a new lesson, they would have to cut another lesson that they had used and they needed to decide if this new lesson would help their students’ learning more than the old lesson. Teachers did discuss however, that time, equipment, and technology were less of a concern if one of the NCLT’s staff members was available to assist in the classroom. Content knowledge was discussed most often from teachers as to why they did not choose more “nano-based” lessons, such as quantum dots and self-assembly, but rather chose intermolecular forces. Teachers were concerned that they did not have a strong enough content knowledge to teach the concept to their students and therefore did not want to introduce the lesson to their students. Again, teachers
commented that if a staff member was present, they were more comfortable in teaching the lesson as someone else would be there to answer student questions.

**Implications**

We have adapted our strategy for lesson planning in the summer institute from these data. We now have more discussions with teachers during the lessons on how each lesson aligns with the standards and where the lessons can fit into the current curriculum. It is our hope that these discussions can show teachers that although these are “new” topics, they are related to the current curricula. Teachers in year 3 (summer 2008) were also limited to writing lesson plans on only four topics (gold nanoparticles/ biosensors, quantum dots, self-assembly, and nano-magnetic materials). This change was made so that we could focus on supporting more highly nano-related implementation. In an attempt to increase content knowledge, we have nano-scientists, engineers, and technologists give presentations to discuss more in-depth nano-content based specifically on the topic(s) the teachers have learned in the nano-lessons on that day. We have also indicated to teachers that members of the professional development staff will be available to assist them in the implementation of their lessons, as support from the professional development team was noted by several teachers as a positive influence to their integration process.

During this school year, we have been observing and interviewing teachers from the summer 2008 institute in their lesson implementation. Although we asked teachers to develop lessons on specific nano-concepts, this did not hinder the teachers from also implementing other lessons such as size and scale and intermolecular forces in addition to their nano-lesson of biosensors, quantum dots, self-assembly, and nano-magnetic materials. We are currently in the process of collecting data from these teachers and are preparing for the follow-up workshop to further discuss their lesson implementation.

This topic is applicable not only to NSE, but parallels can be made to the K-12 engineering curricula as programs try to support teachers in facing barriers to implementing engineering curricula into their science courses. We believe that long-term professional development programs in new content areas can be successful when teachers are given ample content knowledge of the concepts and support throughout the school year. It is also essential that throughout the program, including summer session and year-long follow-up, teachers are able to discuss with colleagues and support staff about how to incorporate new content knowledge into the classroom. Without these discussions, teachers find it difficult and time-consuming to determine how to incorporate these new ideas with the existing curriculum and standards.

**References**


