AC 2009-1040: TEACHERS’ IMPLEMENTATION OF NANOSCALE SCIENCE AND ENGINEERING INTO THE SECONDARY CLASSROOM: A LESSON PLAN ANALYSIS

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Teachers’ Implementation of Nanoscale Science and Engineering into the Secondary Classroom: A Lesson Plan Analysis

Abstract

This study presents an analysis of ten lesson plans created by teachers as a part of a professional development program on nanoengineering, science, and technology conducted by the National Center for Learning and Teaching in Nanoscale Science and Engineering (NCLT) professional development team. The teacher lesson plans were analyzed across multiple dimensions to provide insights into how teachers plan to integrate new concepts into their traditional curricula. The analysis provided meaningful implications for the design of the professional development experience, and for providing appropriate teacher support in implementing content related to nanoscale phenomena in the secondary classroom.

Introduction

As research developments broaden the scope and capabilities of modern engineering, science, and technology, this new information must be integrated into the educational system at all levels. To prepare students to be competitive researchers, we must start introducing foundational information about new developments into secondary education. One of the most important areas of recent research development is nanoengineering, science, and technology. Nanoscale phenomena have been investigated across multiple disciplines, and have applications in numerous fields, including medicine, environmental science, defense, and electronics development. Additionally, nanoscale phenomena provide a way to integrate engineering and design tasks into the secondary classroom (for example, through a lesson on self assembly that asks students to evaluate multiple factors in designing a model of a self-assembling system). Integration of engineering into the secondary curriculum can be a challenge, particularly within the context of rigid traditional curricula.

Any major development in secondary education must start with teachers. The creation of high quality professional development that engages teachers and takes into account their specific classroom environments and constraints is essential to the integration of new concepts, such as those relating to nanoscale phenomena. One way of assessing the usefulness of new classroom materials, and of investigating where teachers see curricular fit, is by an analysis of teacher lesson plans.

This study examines lesson plans from ten teachers who participated in a professional development institute run by the National Center for Learning and Teaching in Nanoscale Science and Engineering (NCLT). The teachers adapted lessons from a professional development institute on nanoengineering, science, and technology for their own classrooms. Research methodology and major findings will be presented, as well as implications for future professional development.
Review of Literature

The literature on professional development provides a number of strategies for assessing professional development efforts. An overview of these strategies and how they relate to the out professional development program will be discussed. In particular, evaluation of professional development that utilizes teacher lesson plans will be addressed. Both quantitative and qualitative methods have been used to study teacher professional development programs. These studies have several goals: to determine the effectiveness of a professional development program in achieving its goals (for example, bringing about pedagogical or content reform), and to ascertain teacher reactions to a professional development program. Since the study described here uses documents (specifically lesson plans) to evaluate professional development, the use of documents will be the focus of the descriptions.

Many studies have utilized surveys and quantitative feedback measures to ascertain teacher responses to and development from professional development programs. However, Lewthwaite points out that although surveys can monitor change, they may not capture the nature of the change and development.\(^1\) In the case of our study, a mixed-methods approach may be appropriate; in the study by Lewthwaite, teachers were asked to respond to Likert scale questions, but were asked to provide additional comments to clarify their responses.\(^1\) In our analysis of lesson plans, we will use some quantitative ratings of various lesson plan aspects, and we will illustrate these with teacher comments and examples of work to illustrate the points that are made by the quantitative data.

In the study by Lewthwaite, the role of curriculum materials and documents was significant. These documents were used to triangulate qualitative data and provide a framework for understanding teachers’ classroom functioning and the district in which they worked. Likewise, lesson plans can be used as a window into what occurs in a teacher’s classroom; however, in undertaking an analysis of lesson plans, it is important to understand that this does not provide us with a complete picture of how a professional development program is implemented, but rather provides a framework for understanding and interpreting teacher interviews and classroom observations. Thus, Lewthwaite’s study indicates that document analysis can be a meaningful step in qualitative assessment of professional development. This study will contribute to other studies being carried out within the professional development program, such as studies on teacher’s integration of nanoscience into the classroom and teacher’s beliefs about nanoscience and engineering.

While lesson plans have been an important source of information in understanding teacher knowledge and development, it has been under utilized as a tool for evaluating professional development. Since the professional development program described in this study is heavily content-focused, a study of lesson plans can provide critical insights into how teachers take this new content and integrate it into their existing courses. This section will describe research related to lesson planning and how it can be used in the evaluation of professional development programs, particularly those with a content-heavy focus.
A teacher’s lesson plans can provide a unique view into how they organize their classroom and their content knowledge to provide learning experiences to students. An overview of research on teachers’ lesson planning processes will be described, as well as implications for this study. Significant research has been conducted in the area of teachers’ lesson planning practices. This literature can be divided into two primary areas: studies of pre-service teachers’ lesson plans, and studies of practicing teachers’ lesson plans. While the latter have more direct implications for the studies described in this thesis, both are important, given that teachers integrating nanoscience are starting with brand new content.

Studies relating to pre-service teacher lesson planning often use lesson plans to gain an understanding of pre-service teachers’ understanding of instructional design or as part of a larger plan for supervision of student teaching and student learning. They have also been used as a means to help pre-service teachers explicate their developing pedagogical content knowledge. Analysis of pre-service teacher lesson plans answers questions about how student teachers undertake the process of lesson design, and whether or not they contain elements of effective lessons.

A study by Strangis et al. used lesson plans in conjunction with interviews to determine student teachers’ attitudes towards lesson planning and the processes that they went through as they developed their lessons. First, although pre-service teachers recognized the importance of developing goals for their lessons, they tended to develop the instructional sequence first. Second, they found that although the teachers had been exposed to a consistent method of lesson planning, student teachers used more than one approach. The two findings described by Strangis et al. are particularly relevant to our study. One of the major areas of analysis for teacher lesson plans in our study was the use of construct-centered design (CCD), which hinges on designing goals and assessments first, followed by instruction. The fact that student teachers did not follow this model indicates that some practicing teachers, when planning for new content, might not follow a similar model. This is consistent with our results. The second major finding also has significance in terms of teachers’ use of the CCD model. Particularly given that practicing teachers may already have well-defined ways in which they like to plan lessons, it may be difficult for many teachers to apply a new model to a familiar task.

While our study does not involve pre-service teachers, research on pre-service teacher lesson planning still has an impact on our study design. Because teachers are planning lessons for material that is new to them, we may find that teachers face some of the same challenges that pre-service teachers face when planning lessons. They may not face all of the same challenges (a practicing teacher planning for nano, for example, would most likely already have a good understanding of their students’ prior knowledge, and what sorts of lessons and activities might work well for their students); however, research on pre-service teacher lesson planning still has implications for analysis of nanoscience, engineering, and technology lessons.

Research on practicing teacher lesson planning addresses teachers’ attitudes towards lesson planning and the processes that they use to plan their lessons. One study by Sanchez and Valcarcel investigated what teachers do when they plan lessons, and how they view their own lesson plans. They used interviews in combination with teacher lesson plans and reports. In terms of structure of lesson plans, they found that teachers tend to start with the concepts to be
taught, and move to instruction, while assessment is not heavily considered during the planning stages. However, this is in contrast to previous work that suggests that initial teacher emphasis is on instruction rather than learning goals. This may have implications for what we see in teacher lesson plans in terms of emphasizing learning goals, instruction and assessment. Sanchez and Valcarcel also found that teachers did not tend to question the sequence of the unit that was given to them. This is particularly significant to our professional development work, given that we ask teachers to modify or restructure one of the nanoscale phenomena lessons for use in their own classroom. Based on this finding, we might expect that some teachers would be reluctant to engage in this kind of revision.

While there is a large body of research on lesson planning, there is a much smaller body of literature relating to lesson plans as a tool for program evaluation. This literature will be discussed within the context of this study. In particular, the implications of this work for methods will be discussed. Lesson plans can provide a window into a teacher’s classroom. While they should never be considered to be a complete picture of what is occurring in the classroom, lesson plans can be used as a baseline to help researchers gain an understanding of the teacher’s general approach and classroom context. As the study of teachers’ lesson plans will provide a foundation for a number of further studies to be carried out in the classroom, this “baseline” understanding is extremely important.

In evaluating lesson plans, it is important to use a well-developed and organized rubric for analysis. A study of teacher assessors in a Georgia program showed that reviewing a teacher’s lesson plans added little to the evaluation of the teacher’s performance. However, when a structured evaluation instrument or rubric was used to evaluate the lesson plans prior to observation of classes, evaluators were able to more accurately assess teachers’ content knowledge and classroom organization and structure.

Depending on the purpose of the lesson plan analysis, rubrics can be focused on various aspects of the lesson or lesson plan. In a study of the use of a particular strategy for lesson planning, known as the Four Stages of Lesson Planning (FSLP) model, Panasuk and Todd (2005) developed a comprehensive rubric that utilized primarily quantitative data about a teacher’s classroom and organization. The lesson plan evaluation form was clearly broken into segments based on the four stages of lesson planning identified in this program, and ratings from 0 to 3 were established for each factor.

A similar approach was used in developing the rubric for this study. The rubric for this study was developed around the goals of the professional development program, and around the construct-centered design approach to lesson planning that teachers were exposed to during the summer professional development institute. Structuring the rubric around a particular lesson planning structure provides a framework for developing guiding questions and ratings for various areas of focus in lesson plan analysis.

Primarily quantitative data have been used in lesson plan analyses for program evaluations. However, I believe that there is a place for qualitative analyses within the area of lesson plan analyses. While some quantitative data were collected in this study, it is an in-depth study of a small number of lesson plans, and general trends cannot be well-described without providing a
clear context and explanation in the form of qualitative data clips. Lesson plan analysis has been under-utilized as a program evaluation tool, and the qualitative analysis used in the study might provide a different way to approach lesson plans as a means for the evaluation of professional development programs.

Another aspect of design that was investigated in this study was teacher use of a particular lesson planning design process. We introduced this model to our teacher participants in summer 2008, and asked them to use the same model in adapting the professional development lessons for their own classrooms. Construct-centered design (CCD) is also referred to as learning-goals-driven design. This process also bears many similarities to the backwards design model of curriculum planning. In the CCD model, design of instruction and assessments is centered around major goals or concepts for students to learn. The designer asks three major questions:

1. What do I want my students to learn? (learning goals)
2. How will I know my students learned that? (assessment)
3. What will I do to foster this learning? (instruction)

Prior to the 2008 summer professional development institute, we attempted to revise and restructure our lessons around this design philosophy, and in the final assignment for teachers, we asked our participants to adapt a lesson from the institute for use in their own classroom using the CCD model. Within this model, we examined learning goals, instruction, and assessments. Instruction was divided into four phases- opening, concept development, making sense, and application, which is consistent with recommendations from the literature on lesson planning.

**Purpose**

This study examines lesson plans from 10 teachers who attended the 2008 NCLT summer institute at Purdue University and completed lesson plans as a part of their program requirements. The following research questions were addressed:

1. Where do teachers see an opportunity to integrate traditional science courses and nanoscience content?
   i. Which topics in nanoscience do teachers perceive as fitting into their existing curricula?
   ii. How do teachers adapt nanoscience lessons to fit their curricula?
2. How did the lessons that the teachers planned to implement reflect the process of construct-centered design of lesson planning?

These questions were addressed within the framework of previous research in lesson planning and professional development within the context of a summer professional development institute.

**Context**

This study was conducted based on lessons developed by teachers as the culminating project of a two-week professional development institute in nanoeengineering, science, and technology conducted by the NCLT at Purdue University. Participants were teachers from all disciplines of
science as well as high school engineering teachers. During the 2008 summer institute, ten teachers attended and developed lessons. These teachers came from different areas of the country and different types of schools. It is important to note that this is a self-selected group, and research has shown a correlation between the quantity of professional development that a teacher attends and their use of inquiry-based and investigative classroom practice. As a program requirement, each teacher had at least three years of classroom experience. A final requirement of the program was that each teacher was required to implement the lesson that they adapted during the 2008-2009 school year. Academic year follow-up is an important component of the program, and teachers return to Purdue for a follow-up workshop each year in the spring to share their experiences implementing nanoscience and engineering in their classrooms.

During the course of the professional development institute, teachers were exposed to a variety of topics relating to nanoscale phenomena, and were asked to select one of four institute lessons to adapt for their own classrooms. The four topics teachers were asked to choose from included self assembly, nanomagnetism, biosensors, and quantum dots. The decision to limit the choice of lessons was made for two primary reasons. First, in the past, teachers often fulfilled their implementation requirement by teaching the size and scale lesson. The following year, many teachers then implemented a lesson on intermolecular forces. These issues were brought to light by previous research conducted through the NCLT, which reshaped the lesson planning task for the 2008 institute. In order to avoid teachers implementing the “easiest” topic, we asked them to not implement either of those lessons. Second, the lessons from which teachers were allowed to choose were selected because they have the most content relating to the big ideas of nanoscience. In this way, we can ensure that teachers teach lessons that are authentically “nano”.

Several days of the institute were devoted to the lesson design/adaptation process, and teachers presented their lessons in a poster session. During the lesson planning process, teachers collaborated with one another and the institute staff to brainstorm ideas and discuss implementation issues that arose as teachers planned their lessons. During the institute, teachers were introduced to construct-centered design of lessons. They were asked to use this process to adapt the professional development lesson for their classroom by identifying learning goals, instruction, and assessments that were aligned with one another.

Methods

The completed lessons were collected and a rubric was developed to analyze various facets of the lesson plan. Four major aspects were investigated: lesson plan design, fit of nanoscience material within the larger curriculum, use of nanoscale content, and connection to state and national science learning standards. These criteria included in the rubric design were chosen based on the structure and goals of the professional development institute. In this paper, findings from several sections of the rubric will be presented. Since one of the primary institute goals is that each teacher will implement at least one lesson into their classroom during the subsequent academic year, understanding how teachers fit nanoscience into their curricula and what specific topics they are able to fit in their classes are important in shaping future iterations of our professional development program. Additionally, understanding which nanoscience content they chose to implement and how they connected these to some of the central concepts and principles of nanoscience, engineering, and technology (NSET) identified by experts may also provide insight into what topics are more easily implemented and what topics require more development.
for secondary classrooms. Teachers relied on a document that describes the “big ideas” of nanoscience to structure the connections they made within the lesson plan.  

Lesson structure was also investigated, inasmuch as a secondary emphasis of the institute was on lesson design. The professional development institute lessons were developed using a construct-centered design process, and teachers were guided through a similar process during the institute. In particular, we were interested in the teachers’ identification of clear learning goals, development of relevant assessments, and design of instruction that facilitated students’ achievement of the learning goals. Each lesson was analyzed for the presence or absence of these three components and how these three were connected to one another.

Once the major aspects of the lesson plan analysis were identified, guiding questions were developed for each major topic. For each question, a scoring system was developed to allow cross-comparison of lesson plans. After the evaluation of the first several lesson plans, the rubric was revisited and a second iteration was created. This was used to reevaluate the first lesson plans and evaluate all of the other lesson plans. The changes in the second iteration were primarily for clarity and to allow easier comparison between lesson plans. In this study, findings related to curricular fit and inclusion of the “big ideas” of nanoengineering and science will be presented.

Data were examined for each area of analysis, and general trends were identified among the findings for each question. This was accomplished through coding each response according to the rubric (quantitative) and looking for key words and themes (qualitative). These trends are discussed in the results section, with examples of the data provided to give an idea of how lessons were compared across each dimension. Once findings for each question were determined, general trends that cut across domains of analysis were identified and described. These general trends are identified as assertions.

**Results and Discussion**

**Curricular Fit**

One of the most important factors in implementing new information into a course is where it will fit within the broader curriculum. With an emphasis on standards-based education and increased teacher accountability, one of the concerns that we most often hear from teachers is that nanoscience material doesn’t fit into the existing courses that they teach, and they do not have time in the school year to add new, innovative materials to their classes. Therefore, it is important to understand where teachers believe nano can fit into what they already teach. Across the board, this seems to be a priority for the majority of teachers. Compiling information about how teachers connect nano to their existing curricula will allow us to provide new ideas to our participants about integrating NSET content, and may also have impacts on how we structure our lessons to address some of these curriculum connections.
The guiding questions identified to investigate how teachers fit nano into the broader curriculum were:

1. With what unit/major topic does the teacher identify this lesson?
2. What is the role of the lesson within the unit? (e.g. presentation of a major unit concept, application of a major concept, or extension to a minor concept.)

Table 1 provides an overview of the four lessons and where teachers are implementing them in the curriculum (i.e. which major unit of the course, such as intermolecular forces or the electromagnetic spectrum).

<table>
<thead>
<tr>
<th>Lesson Topic</th>
<th>Course</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biosensors</td>
<td>Chemistry, Physics</td>
<td>Electromagnetic Spectrum</td>
</tr>
<tr>
<td></td>
<td>Chemistry</td>
<td>Electromagnetic Waves, Electrolytes</td>
</tr>
<tr>
<td></td>
<td>Biology</td>
<td>Central dogma, cells, electrolytes</td>
</tr>
<tr>
<td></td>
<td>Chemistry</td>
<td>Electrons and the Periodic Table</td>
</tr>
<tr>
<td>Biosensors/Quantum Dots</td>
<td>Biology, Chemistry, Marine Science</td>
<td>Color and size-dependent properties</td>
</tr>
<tr>
<td>Nanomagnetism</td>
<td>Physics</td>
<td>Magnetism</td>
</tr>
<tr>
<td></td>
<td>Physics</td>
<td>Magnetism</td>
</tr>
<tr>
<td></td>
<td>Physics</td>
<td>Magnetism</td>
</tr>
<tr>
<td>Self Assembly</td>
<td>Chemistry (Honors)</td>
<td>Intra/Intermolecular forces</td>
</tr>
<tr>
<td></td>
<td>Chemistry</td>
<td>Forces</td>
</tr>
</tbody>
</table>

It is clear from Table 1 that teachers who adapted the same lesson tended to teach similar subjects and incorporate the nanoscience lesson into similar units. For example, all three teachers whose primary subject taught was physics opted to adapt the nanomagnetism lesson as a part of (or as their entire) magnetism unit. There are several reasons that this is likely to have occurred. First, magnetism is an accepted part of current physics classes, and is covered in state and national standards. Therefore, a lesson on nanomagnetism is a fairly straightforward next step in the development of that particular unit, requiring very little “tweaking” of current materials for successful inclusion. Second, the lesson on nanomagnetism from the professional development institute is presented as a unit on magnetism unto itself. Several more traditional activities on magnetism precede the part of the lesson that delves into the relevant nanoscience phenomenon. This may make it easier for teachers to envision how it can be integrated into current course material.

More variation in terms of curriculum fit was evident among the other nanoscale phenomena topics. Although a majority of teachers related the biosensors lesson to the electromagnetic spectrum, for example, the biology teacher who adapted this lesson focused more heavily on the biosensor itself, using biosensors as a way to solidify concepts relating to the central dogma, and introducing the idea of electrolytes. One teacher, who adapted both the biosensor and quantum
Both teachers that chose self-assembly as the NSE content area they would integrate developed it as part of a unit on forces. One of these teachers was much more specific than the other about what this meant, however, and significantly restructured the guiding questions and learning goals to directly address intermolecular forces with this lesson. The other teacher connected the lesson to forces, but used self-assembly more as an application of forces than as a primary teaching tool. An example of a lesson that was adapted to fit into the broader curriculum is the lesson plan that combines both biosensors and quantum dots. This particular lesson plan is interesting because it provides an outline for an entire unit to cover color, the electromagnetic spectrum, and the idea of size-dependent properties (one of the big ideas in nano) as the major focuses. It is also contextualized around saving the manatee, an issue important to students in Florida, where this teacher will be implementing the lesson. This is an example of a lesson where the nano is in the forefront of a traditional curriculum unit (light and color) and developed for a very specific population of students.

Difficulties arose for some teachers in trying to integrate the nanoscale phenomena concepts into existing curriculum units. One of the teachers adapting the biosensors lesson developed it for a unit on the electromagnetic spectrum, for example. However, based on the structure of this teacher’s classroom, the students would not yet have key information on bonding, electrostatic attraction/repulsion, and electrolytes necessary for understanding. Instead of adapting the lesson to fit later on in the course, when students would have the requisite knowledge to handle all parts of this topic, the teacher chose to put the lesson where it fit “best”, and tell the students enough information to allow them to complete their work. This is an example of a possible roadblock in implementing nano — where it doesn’t neatly fit, it is difficult to adapt the focus of the lesson or the structure of the unit to allow the lesson to be meaningful for students. Differences between nanoscale content topics arose based on how they were presented. For example, because the biosensors lesson was not presented as part of a unit, teachers were a bit more creative about its placement in the curriculum. This is beneficial to us, in that we are able to get new ideas from the teachers to improve our existing lessons; however, it may make it somewhat harder to create a coherent lesson that is aligned with the traditional curriculum.

The data on fit into the curriculum tell us that teachers struggle somewhat when the topic is not already aligned with a current unit that they teach. For example, nanomagnetism clearly aligns with the physics unit on magnetism, which made implementation somewhat easier for teachers. Trying to develop curriculum materials for nanoscale phenomena that are not already clearly aligned with a unit of study appeared to be a roadblock for some teachers, although it allowed them to be more creative. This creativity will be discussed further later in the chapter.
Beyond the specific nanoengineering and science topics that teachers chose for implementation, they were asked which of the big ideas of nano their lesson addressed. For the most part, they stated the big ideas listed in the lesson provided by the NCLT (although some identified different big ideas), but teachers integrated the big ideas into their learning goals, instruction, and assessment to varying degrees. This is of concern to the professional development program because we are interested in teachers integrating high-impact topics in nanoengineering and science that emphasize nanoscale phenomena, rather than teachers using nanoscale phenomena as an interesting example without any real focus on the nanoscale concepts involved. The guiding questions for determining which nano content teachers planned to implement were:

1. Which big idea(s) does this lesson address?
2. Are the big idea(s) explicitly stated in the lesson as part of the:
   a. Learning goals?
   b. Instructional sequence?
   c. Assessments?

Table 2 presents a summary of the big ideas covered in the lessons as a whole.

<table>
<thead>
<tr>
<th>Topic of Lesson</th>
<th>Number of Lessons Developed</th>
<th>Classes</th>
<th>Big ideas of nanoscience</th>
</tr>
</thead>
<tbody>
<tr>
<td>Self Assembly</td>
<td>2</td>
<td>Honors Chemistry, General Chemistry</td>
<td>Self Assembly Forces Models</td>
</tr>
<tr>
<td>Biosensors</td>
<td>4</td>
<td>Biology Chemistry</td>
<td>Size-dependent properties Forces</td>
</tr>
<tr>
<td>Biosensors/Quantum Dots</td>
<td>2</td>
<td>Biology Chemistry, Marine Science</td>
<td>Size-dependent properties Quantum Mechanics</td>
</tr>
<tr>
<td>Nanomagnetism</td>
<td>3</td>
<td>Physics</td>
<td>Size-dependent properties Tools and Instrumentation Models Nano and Society</td>
</tr>
</tbody>
</table>

Generally, teachers mentioned the big ideas in the learning goals, but occasionally these big ideas did not come up in the instruction or assessment. There are several possible reasons for this. First, in the process of developing instruction, some of the teachers wound up de-emphasizing the nano content more than they indicated in their learning goals. In these cases, nano was used mostly as an interesting example of the traditional chemistry concept typically covered. For example, in one of the biosensor lessons, although the teacher indicated a desire to teach about biosensors in the learning goals, their main function in the lesson was to replace colored water in a traditional spectroscopy lab as a “hook” to get the students interested.
actual nano phenomena of size-dependent properties and forces were not mentioned in the instructional sequence or assessments.

One of our goals is to help teachers implement concepts that include more nanoscale phenomena (i.e. nanomagnetism is more “nano” than size and scale). Therefore, it is important that we find a way to help teachers integrate the big ideas into instruction and assessment, so that students will be exposed to the fundamental science underlying nanoscale phenomena concepts, rather than just interesting applications of NSET. In general, teachers created high-quality lesson plans that reflected their classrooms and existing curricula. Two general assertions were developed from these lesson plans that summarize the data obtained through the analysis. Implications for professional development and teacher support in lesson planning are also presented.

**Assertion One:** Teachers had a strong tendency to use the professional development lesson plan in its entirely, rearranging their curriculum to fit the lesson rather than the other way around.

This trend appeared throughout nearly all of the lessons. Teachers were given the freedom to use all or part of a professional development lesson or lessons, yet nearly all of the teachers used all parts of one lesson, restructuring their own units if necessary in order to do this. Only two teachers made significant changes in order to make the lessons fit their classroom. One combined two professional lessons and contextualized the unit around viruses and the manatee, and the other used some of the magnetism activities from the nanomagnetism lesson and some from previous experience teaching magnetism. This tendency to use the entire lesson seemed to create problems in some cases — for example, one teacher incorporating a lesson on biosensors into a unit on electrons and the periodic table used the professional development lesson as a whole in the order that it was presented during the institute. However, to do so, she rearranged the sequence of instruction for the unit and introduced material from the next unit earlier than she would have otherwise (rather than introducing part of the lesson with electrons and revisiting biosensors in the next unit).

While it is not necessary for teachers to completely rearrange the lessons if they already fit into their classrooms, our professional development team writes lessons that can be adapted for multiple disciplines and grades 7-12. Therefore, it is hard to imagine that the lessons will fit as a whole within a single unit of a course without some rearranging and adaptation. In the future, we might provide examples of some ways that other teachers have chosen to rearrange or use parts of one or more of the provided lessons to fit their curriculum. Encouraging this adaptation process might reduce pressure on teachers to feel that they need to use an entire lesson, and help them make lessons that work well in their existing classrooms. This should increase the ease of implementation, and the literature on professional development indicates that this should increase the number of teachers actually implementing nanoscience in their classrooms.

**Assertion 2:** Nano was primarily used within a unit as an interesting application of a major concept.

Eight of the ten teachers contextualized nano as an application of major or minor unit concepts. The other two used nanoscience as a vehicle to present major concepts, and three used nano as a vehicle to assist in presentation of major concepts or to present minor concepts. This is not
surprising, given that we made an effort in our lessons to contextualize nano in terms of interesting phenomena and applications. The fact that teachers see nanoscience more as an “add-on” application component rather than a means to teach core unit concepts could be one potential roadblock to implementation, however, for teachers who are already short of time during the school year. A possible implication for our lesson development is to better articulate to teachers how nano can be used to teach some of these core concepts, rather than just reinforce them.

This information about teachers’ use of nano as an application corresponds with the first finding: if teachers feel more comfortable taking pieces of professional development lessons and doing significant revisions and rearrangements, they might find new ways to use nanoengineering and science to teach core concepts. While it is not especially important to us whether nano is used to teach a core concept or to apply it, in terms of ease of implementation, it may be easier if teachers can use it to teach a traditional concept in a new and interesting way. We want to help teachers implement nano in a variety of ways — both as a way to present new concepts and as a way to apply them.

**Conclusions and Implications**

Several major implications for the design of the professional development institute have emerged from this work, relating to instruction during the institute and to teacher support in integration of concepts relating to nanoscale phenomena. In particular, we need to emphasize the development of assessments that correspond to learning goals, help teachers modify lessons effectively for courses that they already teach, and emphasize the inclusion of the big ideas in all phases of the lesson. Emphasizing lesson design will help teachers transition from experiencing nanoscale phenomena to integrating it in their classrooms, and emphasizing the big ideas may help the material being integrated to be more “high impact” in terms of the nano concepts addressed.

Assertion 1 points to a need to help teachers brainstorm ways in which they can make professional development materials fit well into classes that they already teach. To entirely restructure a course or a unit that they have taught before is a tall order for teachers, many of whom cite time as a major factor in their ability to implement new material. In future professional development institutes, we can spend more time with teachers helping them to break down the lessons, and purposefully select the sections of the lesson that best apply to their classrooms. If we can facilitate the lesson development process to help teachers make more useful materials for their classrooms, we might achieve a higher percentage of teachers successfully implementing NSET topics into their classrooms, and continuing to implement in future years. This has implications for other professional development programs that seek to introduce new content into the secondary classroom. It can be a challenge for teachers to take well-developed lessons and completely integrate them into the classroom; thus, teachers need more support in the adaptation process of lessons to fit the needs of their individual classrooms.

A final implication of this study, based on the second assertion, is the need to emphasize the big ideas of nano as an integral part of lesson development. If we want to teachers to really teach nanoscale concepts beyond interesting applications of nano, then we must provide them with support in identifying how to teach broader topics like size-dependent properties, and how they topics relate to what they already teach. Facilitating this process might allow more big ideas of
nanoengineering and science to be fully integrated into assessments and instruction. This also has implications for other professional development programs in engineering or science that attempt to integrate new content. Without an explicit focus on the big ideas, it is tempting to focus on new content only in terms of novel applications, and not as basic knowledge that is important to understand for its own sake. Although nanoscale phenomena have many exciting applications, the fundamental science and engineering concepts in these phenomena are important for students to understand as a part of modern scientific knowledge.

One inherent limitation to a study of lesson plans is that we can only analyze what the teacher records on paper. How the lesson plan will actually be implemented can only be studied within the classroom setting. Ongoing work includes classroom observations of these lessons as they are enacted. Comparison of this observational data to lesson plan data will provide further insight into how nanoscience content is taught in the 7-12 classroom.

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