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A Design-Based Approach to the Professional Development of Teachers in Nanoscale Science

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Nanoscale science is a rapidly-developing, interdisciplinary field of scientific research and development that combines engineering, chemistry, physics, biology, and information technology. It pushes the boundary between the science and the technology required to conduct it. Nanoscale science involves investigating and working with matter on an extremely small scale[1] and has broad societal implications for new technologies. It is estimated that the worldwide workforce necessary to support the field of nanoscale science and nanotechnology will be close to 2 million by 2015 (National Nanotechnology Initiative, 2005). The implications of such rapid scientific advances in nanoscale science require a commensurate response in the science education community to develop and provide *nanoscale science education* (NSE) -- the learning experiences necessary for this workforce to understand the principles that govern behavior of materials at the nanoscale and to develop the skills needed to apply these concepts to improve every day life.

In response to these challenges, a multi-institutional *National Center for Learning and Teaching* (NCLT) was created that focuses on "learning and teaching though inquiry and design of nanoscale materials and applications" (Chang, et al., 2004). The NCLT aims to develop the next generation of leaders in NSE teaching and learning, with an emphasis on nanoscale science and engineering capacity building, and thereby will provide a strong impact on our national STEM education. This interdisciplinary focus serves as an organizing principle for the NCLT, unifying its diverse agents and activities around the common task of learning and teaching the impact of nanomaterials on future industry and technologies. While a limited amount of NSE curricular materials are available for K-12 education, the field is so new that many critical

[1] "Nano" means 10^{-9}. A nanometer is one billionth of a meter. In nanoscale science, objects are measured in nanometers.

questions remain unanswered, including: What are the “big ideas” in nanoscience that should be taught? What concepts are developmentally appropriate for various ages? What prerequisite knowledge, skills, and dispositions do science teachers need for teaching nanoscale science? The research reported in this paper focuses on one component of the NCLT that is intricately engaged in seeking answers to such questions—the NCLT professional development (NCLT-PD) programs in nanoscale science education.

Overview of NCLT-PD

An interdisciplinary team of scientists, science educators, assessment specialists, graduate students and a high school “master teacher” collaborated in the design and implementation of the NCLT-PD experience. The NCLT-PD experience, involving both a summer institute and academic year follow-up activities, was designed with the following instructional goals:

- Science
    - Provide grade 7-12 science teachers with an enhanced understanding of nanoscale science and technology;
    - Enhance teachers’ awareness of the connections between nanoscale science and technology and the traditional sciences of chemistry, physics, biology, earth science, and mathematics.
- Pedagogy
    - Enhance teachers knowledge and skills for using inquiry-based methods (such as the role of evidence and explanation in inquiry) for teaching nanoscience;
    - Promote reflection on salient issues involving teaching and learning through inquiry;

- Provide grade 7-12 science teachers with a collection of suitable classroom activities that they can adapt for classroom use.

Each year for at least the next three years, the NCLT-PD experience will be offered at partnering institutions. In 2006, the NCLT-PD was conducted at Purdue University and University of Texas, El Paso. This paper focuses on the NCLT-PD at Purdue University.

Guiding Principles

To reach the aforementioned instructional goals, the NCLT-PD was conceptualized and designed based on two sets of principles rooted in contemporary and time-honored research on how people learn (*learning principles*) and research on effective professional development (*design principles* for professional development). Modeled after the work of Hawley and Valli (1999) and Alexander and Murphy (1998), we articulate in this section both learning principles and the design principles for professional development that underpin all aspects of our work—from the overall conceptualization and structure of the PD experience to the individual learning activities for each component of the PD experience and the research that supports and extends the design of the PD experience.

Learning Principles

Learning principles reflect our core beliefs about how people learn and factors that influence the learning process. They are derived from some of the most basic tenets of learning from decades of research in cognition.

- *Knowledge base principle.* Learning is a revisionary process in that learners are not blank slates when they come to our science/science education classrooms. They have existing understandings, beliefs, and experiences that influence how they interpret new experiences and information. Learning is also a generative process in the sense that learners must expend the mental effort to make sense and build and understanding of new concepts, ideas, and experiences for themselves. Hence, the design of learning experiences needs to take students’ existing knowledge into account, provide them the opportunity to become explicitly aware of their ideas, and help them build/revise their knowledge (Osborne & Wittrock, 1983; Posner, Strike, Hewson, & Gertzog, 1982; Rokeach, 1968; von Glasersfled, 1989, 1996).

- *Reflection/metacognition principle.* Learning, whether about science or how to teach science, is grounded in a system of values, knowledge, and beliefs. Reflection entails not only the purposeful, systematic and critical examination of values, knowledge, and beliefs about what one is learning, but also acting on those aspects that confuse, frustrate, and perplex in order to improve and refine understanding (Dewey, 1933; Schön, 1983, 1987). Metacognition, or awareness of the process of learning, also is a critical ingredient to successful learning. Metacognition consists of two mental processes that occur simultaneously: monitoring and responding--monitoring one’s progress in the process of learning, and responding to feedback from monitoring by continuing, making changes, or adapting one’s strategies as necessary (Flavell, Speer, Green, & August, 1981; Novak, 1985).
- *Motivation principle.* Motivational constructs such as goals, values, self-efficacy, and control beliefs play a significant mediation role in the process of learning. The design of learning experiences must take into consideration the ways in which students' motivational beliefs about themselves as learners and the roles of individuals in a classroom learning community can facilitate or hinder learning (Blumenfeld, 1992; Pintrich & DeGroot, 1990; Pintrich, Marx, & Boyle, 1993; Schiefele, 1992).

- *Development principle.* Learning takes place in stages; that is, growth of knowledge is a progressive construction and revision of cognitive structures, abilities, and processes (Piaget, 1964; Piaget & Inhelder, 1969; Vygotsky, 1986).
- *Social context principle.* While learning is an individual activity, it is also a socially situated process in which learners interact with other members of a community (Cobb, 1994; von Glasersfeld, 1992; Vygotsky, 1986). Social interaction is as much a part of the process of learning as the individual expenditure of mental effort. Learning "is always bound up with, co-dependent with, the participation and activity of Others, be they persons, tools, symbols, processes, or things. How we participate, what practices we come to engage in, is a function of the whole community ecology, or at least of those parts of it we join in with" (Lemke, 1997, p. 38).

These research-based principles had significant implications for our design of the professional development experience for teachers. First, these learning principles guided the instructional approaches that we adopted for our science lessons. The science lessons that we designed were intended not only for the teachers to experience as science learners, but also for teachers to adapt and utilize with their middle or high school science learners. Second, the five learning principles guided our approach to the pedagogical thread of our design for the professional development experience. Adopting the view that learning to teach science is analogous in many ways to learning science, we approached the pedagogical thread to take into account that (a) teachers should engage in experiences that contribute to constructing their knowledge about teaching and learning, rather than passively receiving and accepting information, and (b) constructing pedagogical knowledge and pedagogical content knowledge entails reflection on one's beliefs, values, and attitudes about teaching and learning (Abell &

Bryan, 1997; Bryan & Abell, 1999; Ross, 1989; Schön, 1983, 1987; Van Zee & Roberts, 2001). We recognized that teachers may not be used to employing in their own classrooms the approaches that we advocated; and furthermore, teachers may not have learned science themselves through the use of instructional approaches guided by these learning principles. Hence, it was incumbent upon us as we designed the professional development experiences to take into account that teachers may need to reflectively consider and/or reconsider principles of learning derived from research, as well as how to facilitate learning in their classrooms based on these principles.

Design Principles

Over the last 15 years, a considerable amount of educational literature has amassed that focuses on teacher knowledge, teacher learning, and teacher change. As a result, professional development, and in particular characteristics of effective professional development, has emerged as a topic of study and review. Historically "traditional" professional development of teachers has been bemoaned as a weak, ineffective and "incoherent and cobbled-together non-system" (Wilson & Berne, p. 174), that has little to no effect on teachers' instructional practices (e.g., Consortium for Policy Research in Education, 1996; Corcoran, 1995; Guskey, 1986). However, there appears to be a changing face of professional development—one that calls attention to the importance high standards, coherence, and in-depth learning opportunities for teachers. To this end, researchers have begun to synthesize the literature on what constitutes effective and high-quality professional development (e.g., Garet, Porter, Desimone, Birman, Yoon, 2001; Guskey, 2000; Hawley & Valli,1999; Loucks-Horsley, Love, Stiles, Mundry, & Hewson, 2003; Wilson & Berne, 1999), resulting in a portrait of consensus about the principles of effecting professional development. Our conceptualization of the NCLT-PD was driven by specific recommendations from this consensus on what factors engender the most effective professional development experiences for teachers. Our commitment to providing high-quality professional development in nanoscale science education is reflected in the following design principles:

- *Subject Matter Knowledge (SMK)*. Effective professional development provides numerous and varied opportunities for teachers to build in-depth content knowledge (Hawley & Valli, 1999; Jeanpierre, Oberhauser, & Freeman, 2005; Loucks-Horsley, Love, Stiles, Mundry, & Hewson, 2003; National Research Council, 1996; Supovitz & Turner, 2000). Research in education, and more specifically science education, clearly has demonstrated positive effects on student achievement outcomes for teachers who participate in professional development programs that have a strong focus on subject matter knowledge (Cohen & Hill, 1998; Garet, et al., 2001; Jeanpierre, Oberhauser, & Freeman, 2005; Kennedy, 1998; Supovitz & Turner, 2000). In addition, literature on science teachers' pedagogical content knowledge supports the intuitive notion that a deep, flexible, and coherent understanding of subject matter is prerequisite to the development of pedagogical content knowledge (e.g., Geddis, 1993; Keys & Bryan, 2001; Smith & Neale, 1989; van Dijk & Kattmann, 2006; van Driel, Verloop, & De Vos, 1998).
- *Pedagogical Knowledge/Pedagogical Content Knowledge (PK/PCK).* New subject matter knowledge itself does not effect change in teacher thinking and practice. A significant component of professional development must include the expansion and elaboration of pedagogical knowledge and pedagogical content knowledge, yet at the same time recognize that the development of PK and PCK is integrally linked to teachers' existing

beliefs, knowledge and experiences (Garet, et al., 2001; Hawley & Valli, 1999; Loucks-Horsley, Love, Stiles, Mundry, & Hewson, 2003; Radford, 1998; Supovitz & Turner, 2000; Wilson & Berne, 1999). In essence, professional development learning activities must not only model the instruction advocated in reforms, but also help teachers reflect on the nature of the discipline and their epistemological beliefs vis-à-vis their own experiences as learners and teachers (Bryan, 2003; Luft 2001; Radford, 1998; Supovitz & Turner, 2000; Wilson & Berne, 1999).

- *Program Coherence and Sustained Contact (C&SC).* When a professional development program consists of a coherent set of opportunities for learning, it is more likely to result in enhanced knowledge and skills for teaching (Garet, et al., 2001). Coherence of a program concerns not only the extent to which activities reinforce and build on one another, but also the extent to which the professional development experiences align with local, state, and national standards and assessments (Garet, et al., 2001, Loucks-Horsley, et al., 2003). Effective professional development programs show teachers how to connect their work to specific standards for student performance (Garet, et al., 2001; Hawley & Valli, 1999; Loucks-Horsley, et al., 2003; National Research Council, 1996; Supovitz & Turner, 2001). Furthermore, just as learning science takes time and experience, learning to teach science occurs over a developmental trajectory (Bransford, Darling-Hammond, & LePage, 2005; Feiman-Nemser, 1983). Professional development needs to take into account that teachers must be given time to learn new content and pedagogy, adapt their instruction to reflect what they have learned, and analyze the outcomes of their new/refined knowledge and practice (e.g., student learning). Programs that support teacher learning over time with coherent, sustained contact experiences acknowledge the complexity of teachers' development of knowledge and skills for teaching science (Hawley & Valli, 1999; Luft, 2001).

- *Professional Relationships (PR).* Effective professional development provides opportunities for teachers to interact and collaborate with each other and experts in learning communities in the processes of learning and teaching, both in and out of school contexts (Garet, et al., 2001, Loucks-Horsley, et al., 2003; Radford, 1998; Wilson & Berne, 1999). Professional communication and colleagueship has been shown to sustain motivation for enacting reform (Lieberman & McLaughlin, 1992). When professional collaborations are developed skillfully they can lead to sharing of knowledge and expertise; working together to address common concerns; developing a better understanding of goals for student learning; alleviating teacher isolation, and numerous other benefits (Hawley & Valli; Garet, et al., 2001). In addition, effective professional development supports teachers to develop professional relationships in the context of leadership roles, for example, as teachers of other teachers and promoters of reform (Hawley & Valli, 1999; Garet, et al., 2001; Loucks-Horsley, Love, Stiles, Mundry, & Hewson, 2003).
- *Continuous Assessment and Evaluation (A&E).* Just as teachers are expected to implement what they learn in professional development, those designing professional development should implement what they learn from the teachers. Continuous assessment and evaluation should inform all components and drive the focus and priorities of professional development efforts. Effective professional development is "information rich" (Hawley & Valli, 1999, p. 142) in that multiple sources of information on teaching and learning processes and outcomes contribute to an iterative design and

implementation cycle (Garet, et al., 2001; Hawley & Valli, 1999; Loucks-Horsley, Love, Stiles, Mundry, & Hewson, 2003; National Research Council, 1996).

In the table below, we show the relationship between learning principles and the design principles that guided the design and implementation of the NCLT-PD experience. The alignment between our beliefs about learning and the fundamental principles upon which we designed the NCLT-PD reflects our commitment to developing a learner-centered experience for teachers that will have a positive impact on their effectiveness, and subsequently student learning in nanoscale science.

Table 1. Relationship between Learning Principles and PD Design Principles

	Knowledge Base	Reflection/ Metacognition	Motivation	Development	Social Context
Subject Matter Knowledge	x	x	x	x	x
Pedagogical and Pedagog. Content Knowledge	x	x	x	x	x
Coherence/ Sustained Contact		x	x	x	x
Professional Relationships		x	x	x	x
Continuous Assessment and Evaluation	x	x	x	x	x

Research Methods

Research Approach and Questions

Over the next several years, the NCLT-PD group is pursuing dual, overarching, and research interrelated goals. First, we seek to examine teachers' development of professional knowledge (SMK, PK, and PCK) for teaching nanoscale science, and subsequently students' learning of nanoscale science as a result of their teachers' new and/or refined knowledge. Second, we seek to design effective PD for grade 7-12 teachers in nanoscale science. Hence, we employed a design-based research approach (Bell, 2004; Hoadley, 2004; Sandoval & Bell, 2004) that is resonant with our dual goal focus. Designed-based research "simultaneously pursues the goals of developing effective learning environments and using such environments as natural laboratories to study learning and teaching" (Sandoval & Bell, 2004). In this paper, we report on the first year of the iterative cycle of design, development, and field-testing of the NCLT-PD experience and instructional materials. Each stage of design, development, and field-testing focused on the ultimate goal of building and refining a sustained-contact PD experience that supports grade 7-12 teachers in their development of professional knowledge for infusing nanoscale science into their existing science curriculum.

At this stage of the multiyear project, our intent was to examine the following research questions to inform our design of the NCLT-PD experience:

1. What are teachers' conceptions of nanoscale science? (SMK)
2. What are teachers' conceptions of inquiry? (PK/PCK)
3. How do teachers design inquiry-based nanoscale science instruction? (PK/PCK)
4. What prerequisite knowledge and skills are needed to teach nanoscience concepts? (PK/PCK)
5. How do the "big ideas" in nanoscale science that we taught align with existing local and national standards? (C/SC)

Context

The 2006-2007 NCLT-PD experiences for grades 7-12 teachers to consisted of: (a) a two-week summer institute in July 2006 (schedule in Appendix A); (b) an academic year follow-up seminar in March 2007 (schedule in Appendix A); (c) participants' implementation of inquiry-based, nanoscience-related lessons in grade 7-12 science classrooms with post-lesson reflective analysis (lesson plan template in Appendix E); and (d) opportunities to participate in the following:

- “ncltteachers group” at Yahoo! Groups®
- a ½-day workshop at the Hoosier Association of Science teachers, Inc. (HASTI) annual meeting
- co-present with NCLT staff at a local science teachers meeting (e.g., HASTI, Kentucky Science teacher Association)
- become a “master teacher” and join the NCLT staff at 2007-8 PD sites

The team that developed this PD experience included two faculty co-directors (one professor in the Department of Physics and one associate professor in the Departments of Curriculum & Instruction and Physics); three doctoral students (representing the Departments of Engineering Education, Chemical Education, and Curriculum & Instruction); one master’s student (Department of Curriculum and Instruction), a master teacher (an Indiana high school science teacher), an assessment specialist, and a project manager. In addition, we invited several university science and engineering faculty engaged in nanoscience, engineering, and technology research to present their work to the participants. The team closely collaborated on all aspects of the design. While the implementation was a collaborative effort, the graduate students were assigned to take the lead on all science instructional tasks and some of the pedagogical discussions in the summer institute and follow-up activities. This team-based approach to implementing the PD experience was resonant with one of the NCLT goals of preparing “the next generation of leaders in nanoeducation, research and technology, and unite them into a close-knit NSEE community” (Chang, et al., 2004).

The science content of the NCLT-PD was organized into 5 major strands central to understanding nanoscience: (1) size and scale; (2) structure of matter; (3) properties of matter; (4) fabrication; and (d) visualization/tools. During science content lessons, teachers engaged in instructional lessons (i.e., investigations, demonstrations, discussions) that modeled the type of inquiry-based instruction that the NCLT is developing for 7-12 science classrooms. Below is a description of the lessons that focused on modern nanotechnology topics:

- Allotropes of carbon: This topic included modeling the idea of a space elevator with composite materials, creating models of nanotubes and buckyballs, and presentations and discussions on the discovery of the allotropes of carbon, their properties, and their applications.
- Self-assembly: These activities were guided by the questions: "What is self-assembly?", "What causes components to self-assemble?", and "What are examples of self-assembling systems?" To answer these questions, teachers read a series of news articles on products made with self-assembly processes, manipulated a computer simulation of self-assembling molecules, and designed a self-assembling system using magnets, Velcro, and Legos®. Research seminars and large group discussions supplemented their knowledge on the principles of self-assembly.
- Scanning probe microscopy: To understand the principles of the atomic force microscope, teachers designed their own probe to map a Lego® surface. For the magnetic force microscope lesson, teachers mapped a magnetic surface using a functionalized magnetic probe. Discussions on concepts and pedagogy were included following each activity and research presentations and a demonstration of a real AFM used in research provided teachers with a better understanding of scanning probe microscopy.
- Nano-based products: The lesson began with teachers investigating the claim of Nanotex® pants to repel stains and resist spills. Teachers were also given a list of

products claiming to be nano-based. They researched the products to determine what was "nano" about the product and how the product worked.

In addition, participants heard from nanoscientists about their current research. All science content lessons were designed to be closely integrated with science inquiry skills, employed inquiry-based teaching methods, and aligned with national and Indiana state academic standards. Pedagogical discussions and activities were woven throughout the science content lessons. Examples of pedagogical discussions included: how students learn science, dimensions of inquiry-based science, using models and simulations in science instructions, and lesson planning for inquiry-based science. Discussions also included major ideas from the *National Science Education Standards* (National Research Council, 1996) and state academic science content standards. Teachers periodically were asked to write reflective journal entries about pedagogical topics of discussion.

Participants

Twelve middle and high school science teachers participated in the PD experience. Table 1 shows the distribution of gender and science content that participants currently teach. The twelve teachers ranged from two to 27 years of science teaching experience. The highest earned degree of 8 teachers was a Master's degree (6 in education; 2 in science). One teacher was completing a Master's degree. One teacher held a law degree.

Table 2. NCLT PD Institute Participants

	Chemistry	Physics	Chem & Phys	Biology	Gen. Science
Middle School	0	1 male	0	0	2 males
High School	3 females, 1 male	2 males	1 female, 1 male	1 male	0

Data Collection and Analysis. A variety of data sources were utilized to gain insight on the research questions. All teachers completed a pre- and post-program survey of perceptions and attitudes during the summer institute [Appendix B]. Two focus group interviews were conducted by a non-instructional staff member: one at the end of week one and the second at the end of week two. A short (5 question) Likert-scale survey was completed by teachers at the end of each inquiry-based investigation [Appendix C]. Small and large group conversations on models in general and nanoscale phenomena models were audio taped and transcribed. In addition, teachers wrote responses to reflection questions about models [Appendix D]. Participants' written responses to discussion questions and their written notes in their journals were photocopied. Finally, participants' lesson plans were electronically submitted. The lesson plan template can be found in Appendix E. Eleven of the twelve participants submitted their lesson plans. Descriptions of teachers' lesson plans can be found in Appendix F.

The first round of data analysis was conducted independently by four NCLT-PD team members (one faculty member, two graduate students, and the assessment specialist) using a constant comparative method (Patton, 1990). Collectively, the researchers compiled and negotiated a set of assertions based on the initial data analysis. The consensus assertions directed the recoding of data. The findings represent a consensus among researchers.

Findings

Analysis of data yielded findings to support the first iteration of evidence-based redesign and modifications of the NCLT-PD. Findings were organized according to subject matter knowledge, pedagogical knowledge, and pedagogical content knowledge issues. Each of these areas represents individual ongoing research agendas; hence, we report below the information that we have analyzed to date.

What are teachers' conceptions of nanoscale science? (SMK) We examined teachers' perceptions of their level of understanding nanoscience as well as their conceptions of nanoscale science. Two items on the pre and post surveys addressed teachers' perceptions of their level of nanoscience understanding: "I have a good general understanding of what nanoscience entails," '[My lack of knowledge of nanoscience] might inhibit [me] from covering nanoscience concepts in [my] classroom." Comparisons of participants' responses to these items are in Tables 3 and 4.

Table 3. Comparison of Pre and Post Survey Item: "I have a good general understanding of what nanoscience entails." (n=12)

	Strongly Agree	Agree	Disagree	Strongly Disagree	Mean
Pre	1	5	4	1	2.54[2]
Post	8	4	0	0	3.67
Difference	+7	-1	-4	-1	+1.13

Table 4. Comparison of Frequency of Response to Pre and Post Survey Item: "What impediments do you currently see that might inhibit you from covering nanoscience concepts in your classrooms: My lack of knowledge of nanoscience." (n=12)

Pre	11
Post	3
Difference	-8

Regarding their perceptions of their own level of understanding of nanoscale science, teachers self-reported an overall increase in their level of understanding nanoscale science and a decrease in their perception that their lack of knowledge of nanoscience was an impediment to teaching nanoscience concepts in their classroom.

Related to their perceptions of their understanding of nanoscience were teachers' conceptions of nanoscience. We asked teachers' on both the pre- and post survey, "Please briefly explain what nanoscience is or involves." In short, our conception of nanoscience is the following: Nanoscience in the simplest sense is "the study of the fundamental principles of molecules and structures with at least one dimension roughly between 1 and 100 nanometers" (Ratner & Ratner, 2003, p. 7). What is significant about the nanoscale is that it is a qualitatively new scale at which some of the most fundamental principles governing form and function of matter depend on size in a way that is unlike than any other scale (DiVentra, Evoy, & Heflin, 2004; Ratner & Ratner, 2003).

On the pre-institute survey, teachers responded that nanoscience involves:

- Scale
    - small, very small, extremely small (4)
    - atomic and/or molecular level (4)
    - particle level (1)
    - microscopic level (3)
- Materials at a nanoscale (2)
- Use of technology or "machines" (3)

No responses indicated the significant aspect of nanoscience as the transitional place where properties become size-dependent—where properties of the macroscale meet properties such as quantum effects. As Ratner and Ratner (2003) stated, "It's important to understand that the nanoscale isn't just small, it's a special kind of small" (p. 7).

Post-institute survey responses indicated similar responses to the pre-survey with the exception of four out of twelve respondents who placed emphasis on the size dependence of properties at the nanoscale:

- "New and exciting properties that differ from matter of 10e-6 - 10e-7 or larger open up a whole other realm for scientists and technologists to explore."
- "Instead of looking at the properties on an item with a microscope, scientists are looking at the items structure and properties at the atomic level."
- "Manipulating atom[s] to take advantage of the unique properties at that size."

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[2] This mean includes one response placed halfway between agree and disagree.

- "Properties of matter change at the nanoscale."

It is evident from the survey responses that we need to emphasize more clearly the uniqueness of nanoscience beyond its definitional size. While teachers understood how small nano is, most of the teachers' responses did not indicate an understanding of the coupling of size with properties that makes the nanometer level a "magical point" (Roco cited in Ratner & Ratner, 2003, p. 7)

What are teachers' conceptions of inquiry? How do teachers design inquiry-based nanoscale science instruction? (PK/PCK) Two items on the pre- and post-institute survey provided insight into teachers' self-perceptions of their use of inquiry and what inquiry-based instruction entails:

Table 5. Comparison of Pre and Post Survey Item: "I frequently use inquiry-based teaching strategies in my classroom." (n=12)

	Strongly Agree	Agree	Disagree	Strongly Disagree	Mean
Pre	5	5	1	0	3.29[3]
Post	7	4	1	0	3.50
Difference	+2	-1	nc	nc	+0.21

Table 6. Comparison of Pre and Post Survey Item: "I have a clear idea of what inquiry-based instruction involves." (n=12)

	Strongly Agree	Agree	Disagree	Strongly Disagr.	Mean
Pre	6	4	1	0	3.38[4]
Post	8	4	0	0	3.67
Difference	+2	nc	-1	nc	+0.29

Teachers' self-report of inquiry practices and knowledge indicated that almost all teachers began participation in the PD experience with the perception (strongly agreed or agreed) that they frequently use inquiry-based teaching strategies in their science instruction. In addition, ten

[3] This mean includes one response placed halfway between agree and disagree.
[4] This mean includes one response placed halfway between agree and disagree.

teachers strongly agreed or agreed that they have a clear idea of what inquiry-based instruction involves.

On the other hand, qualitative data suggested that while most teachers understand the investigative elements of inquiry-based instruction, there was little evidence of their understanding of the role of evidence and explanation in inquiry, particularly as reflected in the lesson plans they developed. While ten out of eleven teachers included opportunities for students to collect data, only 3 of the 10 teachers' lesson plans included a component in which students were prompted to interpret the data to draw conclusions related to the concept learning goals. In six lesson plans, it was specified that the teacher explain or discuss the main concepts after the investigation. Furthermore, in four lesson plans, the data that students were to collect in the investigation did not constitute appropriate evidence from which they could draw assertions *related to the central concepts* that the teacher stated as guiding the lesson. One lesson plan focused on process skill development, as opposed to content knowledge. Finally, pedagogical discussions also illuminated a prevalent conception that inquiry is a completely discovery-oriented, student-directed process and, as opposed to viewing inquiry as multi-dimensional, with each dimension on a continuum from teacher-directed to student-directed.

Pedagogical Content Knowledge: *What prerequisite knowledge and skills are needed to teach nanoscience concepts? (PK/PCK)* Perhaps the most significant finding in this category concerned the role and use of models in inquiry-based science teaching (Daly & Bryan, in press). The most common conception held by the participants was that models are used in science instruction primarily for "show-and-tell" purposes. In other words, the teachers did not view models as a way for students to collect data, make meaning of data, and generate understanding of a phenomenon. While a range of concepts were addressed in the models of nanoscale phenomena found by teachers, 10 of the 12 models were structural, and only two causal, meaning the model could be manipulated, and an effect seen (Gilbert & Boulter, 2000). Additionally, only one teacher who found a causal model discussed his model with respect to its compatibility with inquiry learning.

During the course of the workshop, teachers were not specifically encouraged to find models that could be used in inquiry-based lessons, but the use of models of nanoscale phenomena in our activities and lessons were for inquiry purposes. We used models in our instruction of nanoscale concepts for the purpose of collecting data, determining patterns in data, and generating evidence-based explanations from data. However, our use of models within the inquiry-based lessons of nanoscale phenomena did not seem to influence the models teachers chose, and while the group generated a list of criteria for choosing models that suggested the ability of a model to invite investigation was an important criteria to consider, only one of the models was presented as one to use in an inquiry setting. A few of the models did incorporate a level of student involvement because teachers intended their students to create the models themselves.

In terms of the nanoscience content represented by their models, one teacher commented that he did not how accurate his model was because he was not an expert on the structure of quantum dots. Because of this comment, the other teachers were asked if they felt they had a strong understanding of the concepts their models addressed. Most of them said they did not do any background research on the topics of their models, but six teachers felt that they already had a good understanding of the topic because they taught related concepts in their classrooms. Six teachers expressed that they did not know how accurate their models were, thus could not fully consider the accuracy criteria in the evaluation of their models.

Coherence and Sustained Contact: How do the "big ideas" in nanoscale science align with existing local and national standards? (C/SC) For this question, we explored teachers' perceptions of the coherence between NCLT-PD instructional materials and their science curricula. Ten of the twelve teachers agreed or strongly agreed that nanoscience the concepts presented in the NCLT-PD fit easily into their existing curriculum. In addition, all twelve teachers agreed or strongly agreed that the NCLT-PD gave them practical ideas that they can use in their classroom. These findings were supported in the lesson plans that the teachers submitted. In most cases, teachers were able to correlate their lesson plans to state content standards. The number of standards matched for each subject is shown in Table 7.

Table 7. Standards addressed by each lesson

Lesson	Designed Grade	Designed Content Area	7	8	Chem	Physics	ICP	Unclear	Total
(1)	7-12	General Science	1	2	0	1	0	0	4
(2)	9-12	Chemistry/Physics	2	4	0	0	0	0	6
(3)	11	Biology/nano	0	0	0	0	0	1	1
(4)	10-12	Physics	0	0	0	3	0	0	3
(5)	10-12	Chemistry	0	0	2	0	0	0	2
(6)	10-12	Chemistry	0	0	3	0	0	0	3
(7)	9-12	Biology/Chemistry	0	0	2	0	0	0	2
(8)	9-12	Physics	0	0	0	Unspec.	0	0	Unspec.
(9)	10-12	Chemistry	0	0	3	0	0	0	3
(10)	8-12	Nano/magnetism/ chemical processes	0	3	6	0	0	0	9
(11)	11	ICP	0	0	0	0	10	0	10
Total	---	---	3	9	16	4	10	1	44

Understandably, teachers looked at specific content standards for the content related to the subject they taught rather than looking across disciplines for other standards. For example, the teacher that designed a lesson for Integrated Chemistry/Physics looked at the ICP standards, finding ten, but did not include standards for 7^{th} and 8^{th} grade science, biology, chemistry, or physics. We did not ask teachers to consider different grades or subject areas when writing their lesson plans, thus we did not expect that they would. However, in retrospect, we realize that requesting that they look outside of their own content areas would provide an opportunity for them to engage in a discussion about the interdisciplinary nature of nanotechnology.

A few of the lesson plans centered around traditionally-taught concepts had extensions that tied in more modern advances in nanoscale science and engineering, such as the atomic force microscope serving as an extension to a size and scale lesson to teach forensic science. The lesson plans created by the teachers suggest that they are much more able to envision improved lesson plans on already-taught topics such as size as scale or intermolecular forces rather than adding in a new lesson on a more modern nanoscale science and engineering topic such as self-assembly. The key to incorporating nanoscale phenomena concepts into middle- and high-school classrooms may be in the form of extensions. A lesson on intermolecular forces could be extended with a discussion of the role intermolecular forces play in self-assembling processes, and how self-assembling processes provide opportunities for building better and specific materials that can be used in biological and computer applications. This type of lesson would incorporate current applications of a traditional topic and allow for discussions on the integrated nature of science.

Discussion

As part of the process of design-based research, the NCLT-PD team plans to implement a number of changes in the next iteration of the NCLT-PD experience based on this research and other research projects related to our program. We situate the following discussion in terms of tensions with which we grappled that led to action in the design cycle process.

Tension between subject matter focus versus pedagogy focus. As mentioned in the findings, teachers came to our summer institute with the general perception that they already possess an understanding of inquiry and teach using inquiry-based methods. We also determined from pre- and post-institute surveys that when asked why they chose to attend our summer institute, all of the participants chose to attend to learn nanoscience content. Only one teacher mentioned as a second reason for coming that s/he wanted to learn about "conceptual models, lesson planning, and inquiry learning." While no teachers from the Purdue group expressed discontent with addressing issues of teaching and learning, two teachers mentioned that we should not spend the time that we did on pedagogy, but instead use some of that time for more content. In addition, while this study does not focus on data from UTEP, a small but vocal group complained about the pedagogical focus, with one participant referring to this component of the institute as "educrap."

However, despite the teachers self-reported level of understanding and implementing inquiry in their own classrooms, lesson plan data revealed that teachers need to revisit and refine their knowledge and beliefs about inquiry-based science instruction. Hence, a tension arose that we considered between the "sexiness" of nanoscale science and the necessity of addressing issues of PK and PCK. We need to negotiate a balance between the need to increase the depth of focus on pedagogy with the teachers' desire to focus more on the "nano." We are reminded that teachers' perceptions influence their learning and motivation to learn, just as student perceptions' influence their learning and motivation to learn. Just as students need interesting examples and applications to "hook" them into studying nanoscience, teachers need such hooks as well. One action that we will take is to more prominently showcase intriguing examples and applications, especially at the very start of the PD experience, as several teachers felt that we did not address the "nano" until the second week of the institute.

In addition, we feel that the pedagogical components of the institute needs to remain, but that our approach should change in that the inquiry focus should be deeper (as opposed to broader). One way to accomplish this is to integrate the pedagogy more seamlessly into the science investigations. A two-tiered “making sense” approach to discussions can follow investigations. The first tier focuses on making sense of the science content. The second tier will engage teachers more explicitly in reflective discussions to identify/critique the specific dimensions of inquiry within the investigations, identify teacher and student roles, and identify evidence that supports their critique of the inquiry nature of the nano investigations. Moreover, as teachers plan their lesson, we will engage them in more explicit reflective writing in which they identify and support with evidence what makes their lessons inquiry-based.

In the future, our PD institute also will need to include instructional activities that facilitate teachers’ understanding of how to use models to generate student understanding during inquiry-based science investigations. The lack of incorporation of models into inquiry-based science lessons may limit student opportunities for the construction of knowledge, especially in nanoscale science education.

Tension between interdisciplinary science content and discipline specific courses. Another tension was illuminated by examining the focus of the lessons. The paucity of lessons that incorporated more modern ideas of nanoscale science and engineering suggests that middle- and high-school educators may not be not clear on where and how to integrate these new topics into their curriculum, even though they identified academic standards related to their lessons and we identified academic standards related to these modern nanoscience topics in our instructional materials. It raises issues for us to address—how meaningful are the academic standards to teachers in their day-to-day planning and teaching? How can we better identify specific units or lessons in which teachers can infuse our materials? Furthermore, while nanoscale science is an interdisciplinary field, our teachers do not teach interdisciplinary courses. How can we help them see the value in interdisciplinary connections and spend time teaching subject matter that they may believe to be extraneous to their courses for which they are already stretched for time? One immediate response to this tension is that we will work more closely with teachers in their classrooms during the academic year as they seek to infuse some of the NCLT-PD instructional materials into their classroom. Several on the NCLT-PD team have K-12 classroom experience and can play a more active role in working with individual teachers to find ways to integrate interdisciplinary nanoscience lessons into existing curricula in ways that the teacher and students find meaningful.

Tension between requiring participation and acknowledging teachers' workload. A third tension that we will address, but that is not reported in the data presented here has to do with the follow-up component of the NCLT-PD experience. The NCLT-PD team grappled with the tension between asking teachers to do "too much" during the academic year and *requiring* that they engage in follow-up experiences that create part of the coherence of this program. We are reminded that this program is voluntary, as opposed to a school-mandated PD program that teachers may have no choice but to participate. On the other hand, we explicate the expectations of participants at the onset of the experience, and teachers are compensated for participation beyond the summer institute. During the 2006-7 implementation, we made all of the program follow-up components voluntary. Ten of the twelve teachers participated in at least one of the follow-up activities, with nine of the ten implementing at least one NCLT-PD lesson plan in their classrooms. This participation rate renewed our vision that participation in the NCLT-PD experience is a year-long *commitment*, not simply participation in a summer course. In the next cycle of the NCLT-PD experience, we will not have voluntary options, but instead expect that teachers will complete all of the follow-up activities (e.g., periodically taking part in the ncltteachers listserv dialogues; presenting at a local meeting and/or attending our session at HASTI; completing a teaching analysis protocol and a student learning analysis protocol for NCLT-related lessons implemented). As we stated in our design principles, we believe that professional development should take into account the developmental nature of learning-- that teachers need time to learn new content and pedagogy, adapt their instruction to reflect what they have learned, and analyze the outcomes of their new/refined knowledge and practice.

Finally, in terms of our emerging research agenda, we found that often what was reported in the pre- and post-surveys was not resonant with qualitative evidence. On one hand this is to be expected, given that the majority of quantitative data collected was self-reported. In addition, the nature of qualitative data allows participants to elaborate and provide more detailed explanations to supplement quantitative responses. On the other hand, it suggests that we need to reexamine the meaningfulness of the quantitative data collection. We are addressing these issues in several ways. For example, to ascertain more meaningful data concerning teachers' change in nanoscience content knowledge, the NCLT is developing a nanoscale science concept inventory that we may pilot this summer. In addition, we will enhance our assessment of teachers' development of knowledge for the specific concepts in the lessons we that teach. Finally, to the existing surveys, we will modify a few ambiguous questions and add an explanation component that will allow teachers' to elaborate on their responses.

Conclusion

Science at the nanoscale level is an emerging field that has significant implications for the future of science education. As science educators seek ways of infusing nanoscale science into existing science curricula, it becomes clear that we must design experiences to enhance teachers' science and pedagogical content knowledge for teaching nanoscale concepts. At the same time that we realize the need for teachers' professional development, we must also take into account what learning science has told us for decades. To this end, our study is a first step in examining teachers' content-, pedagogical- and pedagogical content knowledge related to nanoscience and the implications of their knowledge for the design/re-design of professional development on nanoscale science.

References

Abell, S. K., & Bryan, L. A. (1997). Reconceptualizing the elementary science methods course using a reflection orientation. *Journal of Science Teacher Education*, *8*, 153–166.

Ausubel, D. P. (1 968). *Educational psychology: A cognitive view*. New York: Holt, Rinehart and Winston.

Bell, P. (2004). On the theoretical breadth of design-based research in education. *Educational Psychologist, 39*, 243-253.

Boulter, C., & Buckley, B. (2000). Constructing a typology of models for science education. In J. Gilbert & C. Boulter (Eds.), *Developing models in science education* (pp. 41-57). The Netherlands: Kluwer Academic Publishers.

Bryan, L. A. (2003). The nestedness of beliefs: Examining a prospective elementary teacher's beliefs about science teaching and learning. *Journal of Research in Science Teaching, 40*(9*)*, 835-868.

Bryan, L. A., & Abell, S. K. (1999). Development of professional knowledge in learning to teach elementary science. *Journal of Research in Science Teaching, 36,* 121-139.

Cobb, P. (1994). Where is the mind? Constructivist and sociocultural perspectives on mathematical development. *Educational Researcher, 23,* 13 - 20.

Cocoran, T. C. (1995). *Transforming professional development for teachers: A guide for state policymakers.* Washington, DC: National Governors Association.

Consortium for Policy Research in Education. (1996). *Public policy and school reform: A research summary*. Philadelphia: Author.

Daly, S., & Bryan, L. (in press). Models of nanoscale phenomena as tools for engineering design and science inquiry. *Proceedings of the American Society for Engineering Education*.

Darling-Hammond, L. (1997). *Doing what matters most: Investing in quality teaching.* New York: National Commission on Teaching and America's Future.

Dewey, J. (1933). *How we think: A restatement of the relation of reflective thinking to the educative process.* Boston: DC Heath

Di Ventra, M., Evoy, S., & Heflin, J. (Eds.). (2004). *Introduction to nanoscale science and technology*. New York: Springer.

Feiman-Nemser, S. (1983). Learning to teach. In L.S. Shulman & G. Sykes (Eds.), *Handbook of teaching and policy* (pp. 150-171) New York: Longman.

Flavell, J., Speer, J. R., Green, F. L., & August, D. L. (1981). The development of comprehension monitoring and knowledge about communication. *Monographs of the Society for Research in Child Development, 46*(5, Serial No. 192).

Garet, M., Porter, A., Desimone, L., Birman, B., & Yoon, K.S. (2001). What makes professional development effective? Results from a national sample of teachers. *American Educational Research Journal, 38*, 915-945.

Guskey, T. R. (1986). Staff development and the process of teacher change. *Educational Leadership*, *42*(7), 57-60.

Hawley, W. D., & Valli, L. (1999). The essentials of effective professional development: A new consensus. In G. Sykes & L. Darling-Hammond (Eds.), *Handbook of teaching and policy.* New York: Teachers College.

Hoadley, C. M. (2004). Methodological alignment in design-based research. *Educational Psychologist, 39*, 203-212.

Jeanpierre, B., Oberhauser, K., & Freeman, C. (2005). Characteristics of professional development that effect change in secondary science teachers' classroom practices. *Journal of Research in Science Teaching, 42,* 668-690.

Keys, C., & Bryan, L. A. (2001). Co-constructing inquiry-based science with teachers: Essential research for lasting reform. *Journal of Research in Science Teaching, 38,* 631-645.

Lemke, J. (1997). Cognition, context, and learning: A social semiotic perspective**.** In D. Kirshner & J. Whitson (Eds.), *Situated cognition: Social, semiotic, and psychological perspectives.* Mahwah, NJ: Lawrence Erlbaum Associates.

Lieberman, A., & McLaughlin, M. (1992). Networks for educational change: Powerful and problematic. *Phi Delta Kappan, 73,* 673-677.

Loucks-Horsley, S., Hewson, P.W., Love, N., & Stiles, K.E. (1998). *Designing professional development for teachers of science and mathematics.* Thousand Oaks, CA: Corwin.

Luft, J.A. (2001). Changing inquiry practices and beliefs: The impact of an inquiry-based professional development programme on beginning and experienced secondary teachers. *International Journal of Science Education, 23,* 517–534.

National Nanotechnology Initiative. (2005). National Nanotechnology Initiative Education Center. Retrieved November 12 from http://www.nano.gov/html/edu/home_edu.html.

National Research Council. (1996). *National science education standards.* Washington, DC: National Academy Press.

National Staff Development Council (NSDC). (2001). *Standards for staff development*. Oxford, OH: National Staff Development Council.

Novak, J. D. (1 985). Metalearning and metaknowledge strategies to help students learn how to learn. In L. West &A. Pines (Eds.), *Cognitive structure and conceptual change* (pp. 189-207). New York: Academic Press.

Osborne, R. J., & Wittrock, M. C. (1 983). Learning science: A generative process. *Science Education, 67*(4), 498-508.

Patton, M. Q. (1990). *Qualitative evaluation and research methods* (2nd ed.). Newbury Park, CA: Sage.

Piaget, J. (1964). Cognitive development in children. *Journal of Research in Science Teaching, 2,* 176-186.

Piaget, J., & Inhelder, B. (1969). *The psychology of the child.* New York: Basic Books.

Pintrich, P. R., & De Groot, E. V. (1990). Motivational and self-regulated learning components of classroom academic performance. *Journal of Educational Psychology, 82,* 33-40.

Pintrich, P. R., Marx, R. W., & Boyle, R. A. (1993). Beyond cold conceptual change: The role of motivational beliefs and classroom contextual factors in the process of conceptual change. *Review of Educational Research, 63(2), 167-199.*

Posner, G. J., Strike, K. A., Hewson, P. W., & Gertzog, W. A. (1982). Accommodation of a scientific conception: Toward a theory of conceptual change. *Science Education, 66,* 211–227.

Radford, D., L. (1998). Transferring theory into practice: A model for professional development for science education reform. *Journal of Research in Science Teaching, 35,* 73-88.

Ratner, M., & Ratner, D. (2003). *Nanotechnology: A gentle introduction to the next big idea.* Upper Saddle River, NJ: Prentice Hall

Rokeach, M. (1968). *Beliefs, attitudes and values: A theory of organization and change.*

San Francisco: Jossey-Bass.

Ross, D. D. (1989). First steps in developing a reflective approach. *Journal of Teacher Education*, *40*(2), 22–30.

Sandoval, W. A., & Bell, P. (2004) Design-based research methods for studying learning in context: Introduction. *Educational Psychologist, 39,* 199-201.

Schiefele, U. (1991). Interest, learning, and motivation. *Educational Psychologist, 26,* 299-323.

Schön, D. A. (1983). *The reflective practitioner*. New York: Basic Books.

Schön, D. A. (1987). *Education the reflective practitioner: Toward a new design for teaching and* learning in the professions. San Francisco: Jossey-Bass.

Supovitz, J. A., & Turner, H. M. (2000). The effects of professional development on science teaching practices and classroom culture. *Journal of Research in Science Teaching, 37,* 963-980.

Van Dijk, E. M., & Kattmann, U. (in press). A research model for the study of science teachers' PCK and improving teacher education. *Teaching and Teacher Education.*

Van Driel, J. H., Verloop, N., de Vos. (1998). Developing science teachers' pedagogical content knowledge. *Journal of Research in Science Teaching, 35, 673-695.*

Van Zee, E. H., & Roberts, D. (2001). Using pedagogical inquiries as a basis for learning to teach: Prospective teachers' reflections upon positive science learning experiences. *Science Education*, *85*, 733–757.

Von Glasersfeld, E. (1989). Cognition, construction of knowledge, and teaching. *Synthese, 80,* 121-140.

Von Glasersfeld, E. (1992). Constructivism reconstructed: A reply to Suchting. *Science and Education, 1,* 379-384.

Von Glasersfeld, E. (1996). Introduction: Aspects of constructivism. In Fosnot, C.T. (Ed.), *Constructivism: Theory, perspectives, and practices* (pp. 3–7). New York: Teachers College Press.

Vygotsky, L. (1986). The development of scientific concepts in childhood: The design of a working hypothesis. In L. Vygotsky, *Thought and language* (pp. 146-209). Boston: MIT Press.

Wilson, S. M., & Berne, J. (1999). Teacher learning and the acquisition of professional knowledge: An examination of research on contemporary professional development. *Review of Research in Education, 24,* 173-209.

Appendix A
Summer Institute Schedule and Follow-Up Seminar Schedule

Summer Institute Schedule: Week 1

	Sunday 9-Jul	Monday 10-Jul	Tuesday 11-Jul	Wednesday 12-Jul	Thursday 13-Jul	Friday 14-Jul	Saturday 15-Jul	Sunday 16-Jul
8:30 AM		Welcome (PHYS 154)	Discussion - Eliciting Students' Conceptions (PHYS 154)	Discussion - Models, Simulations and Interpretations (PHYS 154)	Activity - Allotropes of Carbon (PHYS 154)	Lab Tour - Growing Nanotubes (Birck Nanotechnology Center)		
8:45 AM		Pre-Institute Assessment - Bill Fornes (PHYS 154)						
9:00 AM				Discussion - Inquiry in the Classroom (PHYS 154)				
9:15 AM		Activity - Size and Scale (PHYS 154)						
9:30 AM								
9:45 AM								
10:00 AM		Break	Break	Break	Break	Break		
10:15 AM		NCLT Overview (PHYS 154)	Activity - Structure of Matter (PHYS 154)	Activity - Intermolecular Forces (PHYS 154)	Discussion - Allotropes of Carbon (PHYS 154)	Activity - Self-Assembly (PHYS 154)		
10:30 AM							No Activities Planned! Weekend RecSports Hours RSC: 8:00 AM - 6:00 PM (Sat) 11:30 AM - 6:00 PM (Sun) Pool 11:30 AM - 4:30 PM Weekend Meals at Earhart Breakfast 7:00 - 8:30 AM Lunch 11:00 AM - 1:00 PM Dinner 5:00 - 6:30 PM	
10:45 AM		Seminar - Nanotechnology Overview (PHYS 154)						
11:00 AM								
11:15 AM								
11:30 AM		Lunch (Earhart)	Lunch (Earhart)	Lunch (Earhart)	Lunch (PHYS 242) Seminar - Properties of Carbon Nanotubes	Lunch (Earhart)		
11:45 AM								
12:00 PM								
12:15 PM								
12:30 PM								
12:45 PM								
1:00 PM		Activity - Putting Nano-Tex to the Test (PHYS 154)	Activity/Discussion - Models, Simulations and Interpretations - (PHYS 154)	Activity - Intermolecular Forces - (PHYS 154)	Activity - Allotropes of Carbon (PHYS 154)	Activity - Self-Assembly (PHYS 154)		
1:15 PM								
1:30 PM		Institute Requirements (PHYS 154)						
1:45 PM								
2:00 PM		Activity/Discussion - Size and Scale (PHYS 154)		Activity - All About Forces (PHYS 154)				
2:15 PM								
2:30 PM								
2:45 PM		Break						
3:00 PM	Registration (Hillenbrand Main Office)	Size and Scale - (PHYS 154)	Break	Break	Break	Break		
3:15 PM			Activity/Discussion - Models, Simulations and Interpretations - (PHYS 154)	Activity - Bending Glass Tubing	Activity - Allotropes of Carbon (PHYS 154)	Discussion - Review of Week (PHYS 154)		
3:30 PM								
3:45 PM								
4:00 PM								
4:15 PM								
4:30 PM								
5:00 PM	Dinner	Dinner	Dinner	Dinner	Dinner	Dinner		

Summer Institute Schedule: Week 2

	Monday 17-Jul	Tuesday 18-Jul	Wednesday 19-Jul	Thursday 20-Jul	Friday 21-Jul
8:30 AM 8:45 AM 9:00 AM 9:15 AM	Lab Tour - Nanomaterials (BRWN)	Activity/Discussion - Scanning Probe Microscopy (PHYS 154)	Activity/Discussion - Nanoscience in Daily Life (PHYS 154)	Lab Tour - Birck Nanotechnology Center	Activity - Lesson Plan Presentations (PHYS 154)
9:30 AM 9:45 AM				TBD	
10:00 AM	Break	Break	Break	Break	Break
10:15 AM 10:30 AM 10:45 AM 11:00 AM 11:15 AM	Seminar - Microscopy - (PHYS 154)	Activity/Discussion - Scanning Probe Microscopy (PHYS 154)	Activity/Discussion - Nanoscience in Daily Life (PHYS 154)	TBD	Activity - Lesson Plan Presentations (PHYS 154)
11:30 AM	Lunch (Earhart)	Lunch (Earhart)	Lunch (Earhart)	Lunch (PHYS 242)	Lunch (Earhart)
11:45 AM 12:00 PM 12:15 PM 12:30 PM 12:45 PM				Seminar - Moore's Law and the Future of Electronics	
1:00 PM 1:15 PM 1:30 PM 1:45 PM	Activity - Scanning Probe Microscopy (PHYS 154)	Activity - Lesson Planning (PHYS 154)	Laboratory Tour - Atomic Force Microscopy (PHYS B47)	Activity - Lesson Planning (PHYS 154)	Post Institute Evaluations (PHYS 154) Activity - Assessment Focus Group (PHYS 242)
2:00 PM 2:15 PM 2:30 PM 2:45 PM			Discussion - Critique of Nanomodels (PHYS 154)		
3:00 PM	Break	Break	Break		Break
3:15 PM 3:30 PM 3:45 PM 4:00 PM 4:15 PM 4:30 PM 4:45 PM	Activity/Discussion - Scanning Probe Microscopy (PHYS 154)	Activity - Lesson Planning (PHYS 154)	Activity -Lesson Planning (PHYS 154)		Final Thoughts (PHYS 242)
5:00 PM	Dinner (Earhart)	Dinner (Earhart)	Dinner (The Trails)	Dinner (Earhart)	Dinner (Earhart)

NCLT Professional Development Follow-Up Seminar Schedule

Friday, 2 March 2007

8:15	Depart University Inn for Purdue University
8:30	Arrive at Burton Morgan Entrepreneurial Center, Room 129
8:30	Poster session set-up
8:45	Welcome
9:00	Interactive Poster Session on Lesson Plan Piloting and Discussion
10:30	Depart for Physics Building
10:45	Arrive at Physics Building, Room 150
11:00	Nanoscience Activities on Lithography and Ferrofluids
12:30	Lunch, Physics Building, Room 398 Dr. Alex Wei, speaker
1:30	Nanoscience Activities on Lithography and Ferrofluids
5:30	Depart for Dinner at The Trails
6:00	Dinner, The Trails Dr. Shawn Stevens, speaker
8:00	Depart for University Inn and Conference Center

Saturday, 3 March 2007

8:15	Depart University Inn for Purdue University
8:30	Arrive at Burton Morgan Entrepreneurial Center, Room 129
8:30	Big Ideas in Nanoscale Science
10:30	Assessment and evaluation activities
12:00	Wrap-up

Appendix B
Pre- and Post-Program Surveys of Perceptions and Attitudes during the Summer Institute

NCLT Nanoscience Teacher Workshop Pre-program Survey

Name________________________________ Date_______________

Please answer the questions below. Your responses will be used only for assessment purposes and will be kept confidential. While your participation is voluntary, your honesty is greatly appreciated.

1. What is your gender (a) Female (b) Male
2. What is your highest completed degree?
   - (a) Bachelor of Arts
   - (b) Bachelor of Science
   - (c) Master of Arts
   - (d) Master of Science
   - (e) Ph.D. or Ed.D.
   - (f) Other: please specify____________________
3. How long have you taught? _____ years
4. What grade(s) do you currently teach? ___________
5. What subject(s) do you currently teach?
   - (a) General Science
   - (b) Physics
   - (c) Chemistry
   - (d) Biology
   - (e) Other Please specify____________________________
6. What motivated you to participate in the workshop?
7. What do you hope to gain from your participation in the workshop?
8. What other professional development workshops have you previously attended? Please list.

Please indicate the degree to which you agree or disagree with the following statements by checking the most appropriate response for each.

	strongly agree	agree	disagree	strongly disagree
9. I have a good general understanding of what nanoscience entails.	(a)	(b)	(c)	(d)
10. I would like to introduce nanoscience concepts in my classroom.	(a)	(b)	(c)	(d)
11. Nanoscience is interesting.	(a)	(b)	(c)	(d)

12. My students would enjoy learning about nanoscience.	(a)	(b)	(c)	(d)
13. I am confident I can effectively teach nanoscience concepts in	(a)	(b)	(c)	(d)
14. Nanoscience concepts easily fit into my school's science curricula.	(a)	(b)	(c)	(d)
15. I frequently use inquiry-based teaching strategies in my classroom.	(a)	(b)	(c)	(d)
16. I have a clear idea of what inquiry-based instruction involves.	(a)	(b)	(c)	(d)

17. How and where have you previously learned about nanoscience?

18. Please briefly explain what nanoscience is or involves.

19. Why is important for you and your students to learn about nanoscience?

20. Do you currently introduce any nanoscience concepts in your classroom? (a) Yes (b) No

If yes, please describe what ideas/concepts and how.

21. What impediments do you currently see that might inhibit you from covering nanoscience concepts in your classroom? (Check all that apply.)

(a) My lack of knowledge of nanoscience.
(b) Lack of teaching resource and materials.
(c) Nanoscience concepts are too complex to teach to my students' age group.
(d) Nanoscience concepts do not align well with state science learning standards.
(e) Nanoscience concepts do not fit well into existing curricula.
(f) Lack of administration support.
(g) Other: please describe.

21. Introducing nanoscience concepts might help you address what national, state and local science learning standards?

NCLT Nanoscience Teacher Workshop Post-program Survey

Name________________________________ Date________________

Please indicate the degree to which you agree or disagree with the following statements by checking the most appropriate response for each.

	strongly agree	agree	disagree	strongly disagree
1. I have a good general understanding of what nanoscience entails.	(a)	(b)	(c)	(d)
2. I would like to introduce nanoscience concepts in my classroom.	(a)	(b)	(c)	(d)
3. Nanoscience is interesting.	(a)	(b)	(c)	(d)
4. My students would enjoy learning about nanoscience.	(a)	(b)	(c)	(d)
5. I am confident that I can effectively teach nanoscience concepts	(a)	(b)	(c)	(d)
6. Nanoscience concepts easily fit into my school's science curricula.	(a)	(b)	(c)	(d)
7. I frequently use inquiry-based teaching strategies in my classroom.	(a)	(b)	(c)	(d)
8. I have a clear idea of what inquiry-based instruction involves.	(a)	(b)	(c)	(d)
9. The workshop was a worthwhile learning experience.	(a)	(b)	(c)	(d)
10. The workshop's various components formed a coherent whole.	(a)	(b)	(c)	(d)
11. The workshop gave me practical ideas I can use in my classroom.	(a)	(b)	(c)	(d)
12. The workshop challenged me intellectually.	(a)	(b)	(c)	(d)
13. I am happy that I participated in the workshop.	(a)	(b)	(c)	(d)
14. I now have a better appreciation for the value of inquiry-based learning.	(a)	(b)	(c)	(d)
15. The workshop gave me a clearer idea of nanoscience's potential importance.	(a)	(b)	(c)	(d)
16. I am looking forward to using what I learned in the workshop in my own classroom.	(a)	(b)	(c)	(d)
17. I would like to share what I learned in the workshop with my teaching colleagues.	(a)	(b)	(c)	(d)

18. What are the most important things you learned or gained from the workshop?
19. Please briefly explain what nanoscience is or involves.
20. Why is important for you and your students to learn about nanoscience?

21. What impediments do you currently see that might inhibit you from covering nanoscience concepts in your classroom? (Check all that apply.)
    (a) My lack of knowledge of nanoscience.
    (b) Lack of teaching resource and materials.
    (c) Nanoscience concepts are too complex to teach to my students' age group.
    (d) Nanoscience concepts do not align well with state science learning standards.
    (e) Nanoscience concepts do not fit well into existing curricula.
    (f) Lack of administration support.
    (g) Other: please describe.
22. How do you plan to use the ideas, knowledge, and skills you gained over the last two weeks in your classroom?
23. What nanoscience ideas/concepts do you anticipate your students would find interesting?
24. Introducing nanoscience concepts might help you address what national, state or local science learning standards?
25. What do you feel were the workshop's most worthwhile or effective activities?
26. What suggestions could you offer to improve the workshop?

Appendix C

Activity Feedback Form

Activity: **Date:**

Please indicate the degree to which you agree or disagree with the following statements by marking the most appropriate responses.

	strongly agree	agree	disagree	strongly disagree
1. I found the activity engaging. .	(a)	(b)	(c)	(d)
2. The material presented is applicable to my classroom.	(a)	(b)	(c)	(d)
3. I gained a good understanding of the ideas/concepts covered.	(a)	(b)	(c)	(d)
4. The activity was a worthwhile learning experience.	(a)	(b)	(c)	(d)

5. What praise, criticism or other thoughts do you have about the activity? How might the activity be improved?

Appendix D

Reflections on Models and Modeling

1. When do you use models in your classroom?
2. How do you decide what is a good model to use in your classroom?
3. When you present models to your students, what types of discussions do you have about the model itself?
4. If you are deciding between two models of something, how do you pick which one to use?
5. For each of the following sets of models, provide your initial response to the models. Would you use them? Do you think they would be beneficial to your lesson and your students? Then rank the models from 1 (most likely to use) to 3(least likely to use), and provide a detailed explanation of your ranking. Finally comment on how you would present the model you chose in your classroom. (If you do not know what the model represents, you can still comment on what you would consider when deciding whether or not to use it.)
6. Now that you have ranked a variety of models, generate a list of criteria that you use to determine what models you use in your classroom.

Appendix E
Lesson Plan Template

[Title of Lesson]

Author: [Author Name]
Draft Date:[Draft Date]

Content Area: [Content Area]
Grade Level: [Grade Level]

LESSON RATIONALE

Instructional Objectives

[Instructional Objectives]

Standards

[State Standards]

Grade Level

Standard Name and Number

[National Standards]

[Subject Standards]

LESSON PREPARATION

Materials

Item	Number/Amount

Pre-Class Preparation

Getting the Materials Ready

Adaptation/Cautions

Example:

Doing the Lesson

Opening

[Opening Question/Remarks]

NOTE:

- [Special Instructions]

Body

Activity 1 – Name

1. Step 1

2. Step 2
    a. Step 2b
    b. Step 2c
        i. Step 2ci

Follow-up

Assessment

Resources

Appendix F

Descriptions of Teacher-Created Nanoscale Phenomena Lesson Plans

	Title of Lesson	Grade/ Subject	Topic	Description
1	Do You Size Up As A Perfect 10?	7-12/ General Science	Size & Scale	To understand size and scale, the metric system, and powers of ten, students order a set of ten cards with varying objects from largest to smallest. The power of ten, metric prefix, and metric symbol are determined.
2	Does Size Really Matter?	9-12/ Chemistry and Physics	Size & Scale and Scanning Probe Microscopes	This lesson was part of a forensic unit where students identify a criminal based on hair. Students investigate powers of ten, size dependent properties, and various microscopes used in science.
3	Surface Area and Volume	11/ Biology and Nanoscale Science and Engineering	Surface Area, Volume, Scientific Notation	Students determine the surface area and volume of a cube and continually cut the cube in half, determining the new surface area and volume. This lesson follows with extensions on surface and volume of nanoparticles.
4	Hula Hoop Physics: Overcoming Gravity's Pull	10-12/ Physics	Dominance of Forces	An investigation occurs as to how a group of students can lower a hula hoop without allowing their finger to leave the hoop. A discussion of the ease of overcoming gravitational forces versus electric forces takes place.
5	Molecular Attractions: Why do Chemicals Behave the Way They Do?	10-12/ Chemistry	Intermolecular Forces	Students investigate the various types of intermolecular forces and the importance of these forces at the nanoscale while participating in "discovery" activities, group discussions, laboratory, and an application follow-up relating to nanoscience.
6	Intermolecular Forces	10-12/ Chemistry	Intermolecular Forces	The lesson allows students to investigate the relationship between physical properties of liquids and intermolecular forces. The Internet and textbooks are used as an introduction for students to intermolecular forces followed by a laboratory activity.
7	Why Water?	9-12/ Biology and Chemistry	Properties of Water	Students investigate evaporation, capillary action, and specific heat of water and how these properties differ from other liquids. They determine which liquid is best suited for life and make a commercial to sell their liquid based upon their data and results.
8	Mapping a Surface	9-12/ Physics	Scanning Probe Microscopes	Students design and test a method to map the surface of the classroom using a motion detector. An article describing scanning probe microscopy is read followed by a discussion of similarities to and differences from a motion detector.
9	If They Could See Me Now – How Do We See Atoms?	10-12/ Chemistry	Scanning Probe Microscopes	This lesson focused on students creating ways they can "see" without using their eyes. They perform both hands-on and Internet activities on scanning probe and magnetic force microscopy. Students also read an article on DNA origami followed by a group discussion.

10	The Size of Matter Matters! Making Nanosize Clusters of Magnetite in a Ferrofluid	8-12/ Any Science Class	Ferrofluids	The lesson begins with a series of questions for students surrounding magnetism and chemical reactions. Students then synthesize ferrofluids and engage in a group discussion to make sense of the activity including rate and effects of grain size on magnetism.
11	How do You Make Your Favorite Color?	11/ Integrated Chemistry & Physics	Waves (Light and Sound)	The lesson was designed for students to understand that light is both a wave and particle and how LEDs work. Students first explore sound waves and then investigate LEDs compared to a small light bulb.