Can High School Students Learn Nanoscience? An Evaluation of the Viability and Impact of the NanoSense Curriculum

Patricia Schank
Alyssa Wise
Tina Stanford
Anders Rosenquist

SRI International
January 2009

TABLE OF CONTENTS

INTRODUCTION

Nanoscience is the study of phenomena on the scale of 1-100 nanometers (10^{-9} m) and nanotechnology is the manipulation of matter at this scale to create useful products. It is an important area for research and development because the many unique properties of matter at this size scale present the opportunity to revolutionize fields as diverse as medicine, energy and manufacturing. In addition, recent technological developments have greatly enabled the study and manipulation of matter at this scale with similar progress expected to continue. For these reasons, the U.S. Government has identified nanoscale science and technology (NS&T) research and education as an area of high priority (National Research Council, 2002).

The continued expansion and influence of nanotechnology requires a forward-thinking investment in education to create the necessary workforce and to aid in the development of informed citizens and consumers. The National Nanotechnology Advisory Panel members "strongly believe that more needs to be done to bolster the number of nanoscale STEM (science, technology, engineering, and mathematics) graduates and teachers" (President's Council of Advisors on Science and Technology, May, 2005, p. 36). One way to increase the number of students interested in and ready to pursue nanoscience-related careers is to provide them with meaningful and relevant experiences in nanoscale topics in their high-school science classes.

Toward this goal, the NanoSense project (nanosense.org), in collaboration with scientists and partner high-school science teachers, has developed, pilot-tested, and revised four curriculum units that can be inserted whole or in part into high-school science classrooms. The units have been distributed to teachers at professional development workshops and are freely available online (http://nanosense.org). The first unit provides an introduction to nanoscience, focusing on concepts related to size and scale, unique properties at the nanoscale, and tools. The remaining three units each explore the science behind an interesting application: Clear (nanoparticulate) Sunscreen, Clean (nanosolar) Energy, and Fine (nano) Filters. Each unit contains PowerPoint slides (with rich images) and teacher's notes, hands-on activities, labs and student handouts, readings and assessments. To enable teachers from the traditional disciplines to easily find appropriate activities for their class, the development team created alignment charts that show mappings between specific NanoSense activities and standard science curriculum topics.

In the fourth and final year of the project, an evaluation of the curriculum was conducted based on implementation in six high-school classrooms. This report details the goals the evaluation, the specific evaluation questions investigated, the methods by which the evaluation was conducted, and finally, the results of the evaluation and the conclusions drawn from them.

Evaluation Questions

A core motivation for the NanoSense project was the belief that with appropriate teacher preparation and guidance, engagement with well-designed nanoscience curricular activities could help students conceptualize underlying principles that govern the behavior of particles on the nanoscopic scale and improve student attitudes about science by introducing them to emerging ideas of science and compelling, real-world examples of science in action. The NanoSense

Curriculum was developed in an attempt fulfill this promise. The goal of the evaluation was to investigate the degree to which the curriculum was able to accomplish its purpose. The specific evaluation questions were as follows:

1. Does learning the NanoSense Curricula increase students' understanding of nano-related concepts?
    a. What nano-related concepts did students understand and which ones challenged them?
    b. What foundational understandings needed to learn nano-related concepts did students have difficulties with?

2. Does learning the NanoSense Curricula change students' attitudes towards science in general?
    a. Does it make students see science as more relevant to their lives?
    b. Does it make them more interested in a career in science?

3. What features of the NanoSense approach are key supporters of or detractors from its viability as a model for teaching nanoscience to high-school students with respect to the following areas:
    a. Selection of content
    b. Fit with traditional science curricula
    c. Delivery structures for the materials
    d. Teacher professional development

To answer these questions, we implemented the NanoSense materials in classrooms and measured change in student understanding and attitudes through administration of pre- and post-instruments. We also collected representations of student understanding generated in the course of the unit, teacher reflections and researcher observations.

METHOD

Teacher Recruitment

Teachers were recruited from two groups: (1) partner teachers who had collaborated in the development of the units over the previous four years; and (2) teachers who had attended one of the three NanoSense workshops. These were project-hosted professional development workshops at San Jose State University, where teachers attended presentations by NanoSense staff and our partner teachers, participated in hands-on laboratory activities, adapted NanoSense lesson plans for their classrooms, received feedback from peers and instructors, and collaboratively brainstormed ideas for integrating nanoscience into their curriculum.

Throughout Year 3 of the project, we encouraged teachers in our meetings and workshops to implement the units where they best fit with their curriculum, and informed them that if they let us collect data in their class, we would cover the cost of the lab and curriculum materials. The minimum criteria that we required as an implementation for this evaluation was that the teacher used the primary slide set for the unit. In August 2007, we contacted both groups of teachers with a request to let us know when they planned to implement the units and if they would be willing to collect (or let us collect) data on student learning. Although our workshop and partner teachers expressed a great deal of interest in the NanoSense units, and several teachers responded enthusiastically to our requests, follow-through was problematic. These initial requests did not pan out for three main reasons:

1. Several teachers intended to use the units, but did not because of time constraints.
2. Several teachers used only a very small portion of one of the units (e.g., one activity, such as the Size Matters card sort activity).
3. Some teachers implemented large sections of a unit, but did not inform us until after the fact, and administered their own custom pretests and posttests that were not aligned with the goals of the unit.

In January 2008, we conducted a focused push with our partner teachers to schedule implementation studies. We asked them when they could commit to implementing a unit, and gave them three implementation options: (1) they teach the unit in their class, (2) a project team member could co-teach the unit with them, or (3) the project hosts a series of weekend or afterschool workshops for their students (either they or we could teach). In all cases, we offered to provide all the resources they would need (e.g., lab materials, student handouts) and to pay teachers for their time spent in preparation and debriefing. Four teachers (C, G, J, and M) replied that they would implement part of all of a unit; two of these teachers (G and J) chose the co-teaching option, and two (C and M) chose to teach alone. Follow-up discussions indicated that for all four teachers, their knowledge and comfort level with the materials were major barriers to implementation, more so than resources. Teachers told us that they have very little time in the day to prepare for teaching a new unit, let alone on a new topic. This was true despite the fact that these teachers were quite familiar with the units, having participated in their development for three years.

Participants & Implementations

In spring 2008, the four NanoSense units were implemented by four teachers in 11 high-school science classrooms of varying subjects (chemistry, biology, biotechnology, and environmental science) as shown in Table 1. Approximately 200 students participated in total. Size Matters was implemented in one 10^{th} grade chemistry class (36 students). Clear Sunscreen was implemented in one 9^{th} grade biology class (23 students) and two $11^{th}/12^{th}$ grade biotechnology elective classes taught by the same teacher (36 students combined). Clean Energy was implemented in three 10^{th} grade environmental science classes taught by one teacher (44 students combined) and a sheltered $10^{th}/11^{th}$ grade chemistry class (16 students) taught by a different teacher. Fine Filters was implemented in the same three environmental science classes as the Clean Energy unit (44 students combined), two months later. For the purposes of analysis, when one teacher taught the same material to multiple class sections, the data from these sections were analyzed together as a single implementation.

Unit	Teacher	Class	Grade Level	Class Type	# of Class Sections	# of Participants / Total # of Students	# of Class Meetings	Proportion of Unit Materials Used
Size Matters	C	Chemistry	10^{th}	Regular	1	36 / 36	2	Low
Clear Sunscreen	G	Biology	9^{th}	Regular	1	19 / 23	4	High
Clear Sunscreen	G	Biotech	$11^{th}/12^{th}$	Advanced elective	2	35 / 36	1	Low
Clean Energy	M	Environmental Science	10^{th}	High % special needs	3	43 / 44	5	High
Clean Energy	J	Chemistry	$10^{th}/11^{th}$	Sheltered (ESL)	1	13 / 16	3	Moderate
Fine Filters	M	Environmental Science	10^{th}	High % special needs	3	40 / 44	4	High

Table 1: Summary of NanoSense Classroom Implementations

Teacher Background & Preparation

As mentioned above, four teachers participated in the implementation study. Two chose to teach alone, and two chose the co-teaching option. Here we describe each teacher's background and prior experience with NanoSense materials before the implementations.

Teacher C (Size Matters, taught alone)

Teacher C has been teaching high school chemistry and physics for over 20 years, and holds a Master's degree in educational administration. Teacher C participated in NanoSense unit development from the beginning of the project. She attended multiple teacher meetings in which we presented proposed content for the units and solicited and discussed suggestions from the teachers for revisions. In particular, Teacher C participated in 5 two-hour meetings in which the content and design of the Size Matters unit was the primary focus. Teacher C also co-presented (with Teacher G) the One Day Introduction to Nanoscience PowerPoint slide set from the Size Matters unit at a one-day NanoSense workshop for students in February 2006 and attended a half-day NanoSense workshop for teachers in December 2006. At this workshop, NanoSense staff presented the one-day slides, and Teacher C co-led (with Teacher G) demonstrations of hands-on activities from the Size Matters unit. For this implementation, Teacher C elected to teach the selected parts of the Size Matters unit alone.

Teacher G (Clear Sunscreen, co-taught)

Teacher G has been teaching high school biology for over 25 years; for the last 15 she has also taught a biotechnology class. She received her undergraduate degree in German literature and language, with a minor in biology and chemistry from the University of California, has done credential and graduate work at several UC and CSU campuses, is active in teacher education, and serves in leadership roles on local biotechnology education partnerships. Like Teacher C, Teacher G was also involved with the NanoSense project from its beginning. She attended multiple teacher meetings in which we presented proposed content for the units and solicited and discussed suggestions from the teachers for revisions. In particular, Teacher G participated in 5 two-hour meetings in which the content and design of the Clear Sunscreen unit was the primary focus. She co-presented (with Teacher C) the Size Matters one-day slides at the one-day NanoSense workshop for students in February 2006, and attended the rest of the workshop––which focused on the Clear Sunscreen unit—with five of her students. At this workshop she also co-facilitated (with Dr. Wise) the Consumer Choice Pamphlet activity, in which Students create a pamphlet to inform consumers about nanoparticulate sunscreens, how they work, and their benefits and drawbacks.

For this implementation, Teacher G elected to co-teach most of the Clear Sunscreen unit. Teacher G and Dr. Wise (who was the primary author of the unit) collaboratively planned the implementation over the month and a half preceding the implementation through e-mails and phone conversations. Teacher G felt strongly that the students needed some "active time" each class, so Dr. Wise created a customized unit lesson plan that split the PowerPoint presentations and lab activities across multiple days. In addition, Teacher G wanted to begin with the sunscreen labels activity (from lesson 2) to give the students "something concrete for connecting new information" so Dr. Wise made some small modifications to the activity materials to make them appropriate as an introductory activity.

Teacher M (Clean Energy and Fine Filters, taught alone)

Teacher M has been teaching chemistry and environmental science for 3 years. She graduated Summa Cum Laude in 2003 from Cal State Stanislaus with a BS in biology, concentration in genetics and minor in chemistry. Teacher M attended only two NanoSense teacher meetings, but she pilot tested the initial versions of the Clean Energy and Fine Filters units for a full week each in 2007, a year before the implementations described here. The NanoSense team made major revisions to both of these units based upon Teacher M's pilot tests, and Teacher M even co-designed some of the materials in these units. In particular, for the Fine Filters unit, Teacher M co-designed the filtration labs, created a worksheet for the Jarny activity to help students organize their information, and recommended integrating some fundamental chemistry of water into the unit. Teacher M also attended one day of a 4-day NanoSense workshop for teachers, where she observed Dr. Scharberg present the Clean Solar Energy slides for the Clean Energy unit. At the workshop, Teacher M also prepped the Nanocrystalline Solar Cell Lab and led the lab with teachers attending the workshop. For this implementation, Teacher C elected to teach the selected parts of the Clean Energy and Fine Filters units alone.

Teacher J (Clean Energy, co-taught)

Teacher J has been teaching high school chemistry and integrated science for 3 years, after a 10-year break to raise her family. Prior to that, she received her masters in microbiology and an undergraduate degree from Bombay University in chemistry and life sciences (dual major), and took several physics courses. She also taught biology at St Xavier's college India for 6 years. Teacher J joined the project midway through its third year (January 2007), about the same time that Teacher M (see below) joined the project. Teacher J had minimal formal exposure to the materials. She attended two NanoSense teacher meetings, including one in which the Clean Energy unit was the focus of discussion—in particular, drafts of the Solar Cell Technology Teacher Reading and Silicon and Nanocrystalline Solar Cell Animations were presented for discussion, and the teachers suggested several revisions for the reading and the animations.

For this implementation, Teacher J elected to co-teach parts of the Clean Energy unit. She coordinated closely with NanoSense team member Dr. Rosenquist (who was the primary author of the unit) and chemistry professor Maureen Scharberg at San Jose State University through emails and phone conversations. The lessons and activities were used as designed in the unit (i.e., no customizations were made to the lessons or materials).

Classes & Materials Used

All four NanoSense units were implemented in local San Francisco Bay Area classrooms during the spring of 2008. The character of the different implementations (discussed in detail below) was strongly determined by the time the teacher had available. Availability of resources for labs and activities was not a constraint, since the project provided all necessary materials for the NanoSense activities that the teacher chose to do.

The number of class periods devoted to NanoSense instruction varied between one and five; in all cases, classroom periods were approximately 50 minutes in duration. In all implementations, teachers administered a pretest before the intervention (usually during the preceding class), and an identical unit posttest immediately after the intervention. When the pre and post attitude survey was used, it was administered at the same time as the pretests and posttests. Teachers were reminded that they did not have to use all materials from a unit to give the tests, but to let us know what materials were used and if any modifications were made. The length of each implementation and proportion of curricular materials used is summarized in Table 1.

Size Matters

The Size Matters unit was implemented by Teacher C on her own in her 10th grade regular-track chemistry class of 36 students at a high achieving public high school (API of approximately 880). Two days were spent on the unit, and data was collected on all 36 students. The teacher reported that she did not modify the materials at all; however, she did work to emphasize the chemistry relationships (e.g., emphasizing chemical properties like reactivity, physical properties like involvement with intermolecular attractions, and overall size connections to atoms, ions, and molecules). On the first day, the teacher presented the One Day Introduction to Nanoscience slides. This is a summary slide set that covers highlights from each of the five lessons in the unit. On the second day, the teacher led a full period of class discussion about nanoscience in general, emphasizing the chemistry connection. Overall, a very small proportion of the unit materials were used in this implementation. No hands-on activities or labs were conducted.

Clear Sunscreen

The first implementation of the Clear Sunscreen unit was conducted using a co-teaching approach. NanoSense team member Dr. Wise was responsible for leading the interactive PowerPoint discussions, and Teacher G was responsible for all other classroom activities. The class was a regular-track 9th grade biology class of 23 students at a high achieving public high school (API of approximately 900). Four days were spent on the unit and data was collected from 19 of 23 students. A NanoSense research team member was present in the classroom during the implementation to take observation notes. Overall, a relatively high proportion of the unit materials were used in this implementation, including hands-on activities and labs.

Prior to the first class, students were given the Sunscreen Labels Activity to do as homework. On the first class, the students shared the information that they gathered for homework and discussed patterns they saw in the results. This discussion was followed by an interactive presentation of the Introduction to Sun Protection slides. On the second day, the class discussed the Summary of Radiation Emitted by the Sun handout, Dr. Wise presented the All About Sunscreens slides, and the students began work on the UV Bead Lab Activity. On the third day, the students completed the lab and watched a UV light demonstration in which a 50-euro bill was held under two different UV lights to show how different patterns appear under different UV spectra because the embedded chemicals differentially fluoresce in response to different ranges of UV. (The chemicals are embedded as a way to detect counterfeit bills.). On Day 4, Dr. Wise presented the remaining All About Sunscreens slides and the students shared their lab activity data. Results from each group were superimposed on a transparency for discussion. Throughout the unit, students were encouraged to write down insights and questions on index cards.

In addition, Dr. Wise presented a one-day version of the unit to 36 students in two biotechnology classes at the same school. This was an advanced elective; students in these classes had already taken biology and chemistry and many were taking another science course (e.g. physics or an AP science) concurrently. Data was collected from 35 students. The one-day version was a PowerPoint slide presentation that incorporated slides from all of the lessons, along with the 50-euro bill UV light demonstration. A NanoSense research team member took observation notes. No hands-on activities or labs were conducted with the biotechnology students.

Clean Energy

The Clean Energy unit was implemented in two schools. In the first implementation, Teacher M presented the unit on her own to 44 students in her three 10th grade environmental science classes at a high achieving public high school (API of approximately 900). The environmental science classes were an offering for low-performing students as an alternative to standard 10th grade chemistry and had a high proportion of special needs students. Five days were spent on the unit, and data was collected on 43 students. On the first day, the teacher presented the Introduction to Clean Energy slides. On the second day she presented the Solar Energy and Nanoscience slides. On the third day, the students explored the Silicon and Nanocrystalline Solar Cell Animation and completed the accompanying worksheet, and read the Hybrid Cars, Solar Cells, and Nanoscience Student Reading and completed the accompanying worksheet. On the fourth and fifth days, the students completed the Nanocrystalline Solar Cell Lab Activity. A NanoSense research team member assisted with the solar cell lab activity. Overall, a very high proportion of the unit materials were used in this implementation.

In addition, the Clean Energy unit was implemented using a co-teaching approach with Teacher J and Dr. Scharberg in Teacher J's 10th /11th grade sheltered chemistry class of 16 (ESL learner) students at a medium achieving public high school (API of approximately 720). Three days were spent on the unit, and data was collected from 13 students. On the first day of the implementation, Dr. Scharberg presented The Potential of Nanoscience for Energy Production slides from the first lesson of the Clean Energy unit. On the second day, Teacher J presented the Silicon and Nanocrystalline Solar Cell Animation and the class discussed the salient elements of the animation. On the third day, Teacher J and Dr. Scharberg helped the students complete the Nanocrystalline Solar Cell Lab Activity. (The teacher prepped the lab activity by preparing the titanium dioxide slides so that the students could focus on assembling and testing the cells.) NanoSense research team members observed the classroom on the second and third days. Overall, a moderate proportion of the unit materials were used in this implementation, including hands-on activities and labs.

Fine Filters

The Fine Filters unit was implemented by Teacher M on her own in three 10th grade environmental science classes reaching 44 students at a high achieving public high school (API of approximately 900). This implementation was in the same three environmental science classes as the first Clean Energy implementation, but two months later. Four days were spent on the Fine Filters unit, and data was collected on 40 students. On the first day, Teacher M presented the Introduction to the Water Crisis slides and led an interactive discussion as students completed the accompanying Student Data Worksheet. On the second day, the teacher presented the Nanofiltration PowerPoint Slides and the students completed the Which Method is Best worksheet and the Cleaning Jarny's Water activity. On the third and fourth day, the students completed the Comparing Nanofilters to Conventional Filters Lab Activity. A NanoSense research team member visited the classroom and took observation notes. Overall, a high proportion of the unit materials were used in this implementation, including hands-on activities and labs.

Data Sources

The following data sources were collected and analyzed by the NanoSense team to assess student learning and attitude change as a result of the curriculum and assess the viability of key features of the approach for integrating nanoscience into high school classrooms. Only a subset of the data sources was available for some implementations. Table 2 summarizes the exact data sources that were collected for each implementation.

Pre/Post Unit Tests

Short (4-8 question) tests were developed to assess student knowledge of concepts covered in the NanoSense units. Individual tests and accompanying grading rubrics were developed for each unit. The questions aimed to assess student understanding related to the learning goals ("enduring understandings") that drove the development of assessments and activities for each unit. These learning goals are based on core concepts and principles of nanoscience and were vetted by collaborating scientists and teachers. For example, for the Size Matters unit, one (of four) learning goals was, "New tools for observing and manipulating matter increase our abilities to investigate and innovate" and a related question on the pre and posttest was, "What do we mean when we talk about 'seeing' at the nanoscale?"

Teachers were asked to have their students complete the pretest before starting any lessons from a unit, and to complete the posttest after finishing all lessons planned for the unit. The pre and posttests for the appropriate unit were administered in all six of the implementations reported here. Tests for the Size Matters, Clear Sunscreen and Fine Filters Unit had a maximum of 20 points possible while the Clean Energy Unit had a maximum of 12 points possible.

Student Aha/Confusion Cards

As part of our data gathering strategy, teachers were asked to hand out two colors of index cards to their students at the beginning of each class. One color was used by students to write down things they found confusing or had questions about during the lesson(s), and the second color was for them to capture and share "light bulb" or "aha" moments. Teachers were asked to let students know they could fill out the cards at any point during class and that they did not need to put their name on the cards. At one or more points during (or at the end of) the lessons, teachers collected the cards. In addition to serving as a data source for the research, we recommended that teachers use the cards as a tool in their teaching by sharing student "ahas" and address their confusions. Teachers elected to use these index cards in four of the six implementations.

Thoughts About Science Pre/Post-Survey

A six-question survey adapted from Siegel and Ranney's (2003) Changes in Attitude about the Relevance of Science (CARS) questionnaire was used to assess changes in student's attitudes towards science. Items used a five-point Likert scale with 5 indicating a more positive attitude towards science. Teachers were asked to give the presurvey and postsurvey at the same times that they gave the pretest and posttest. However, teachers elected to administer this survey in only four of the six implementations (both implementations for the Clear Sunscreen and Clean Energy Units).

Teacher Reflections

After completing a unit or lesson, teachers were asked to reflect on the implementation by answering a few questions regarding (a) what activities they used, (b) whether they modified the materials in any way to fit their classroom needs, (c) how many periods was the unit implemented and what (if any) homework was given, and (d) their perception of student reactions to the lessons (did students seem interested, did they seem to understand the content, what were any areas of confusion). In most cases, a NanoSense research team member was present to interview the teacher regarding these questions; if not, the teacher was asked to email their answers to the NanoSense team.

Researcher Observations

In addition to the NanoSense team members involved in co-teaching some of the units, in four out of the six implementations, a NanoSense research team member attended some or all of the classroom sessions. These researchers took notes on various aspects of the implementation, including classroom composition (number, gender, and ethnicity of students), what materials and activities were used, if the materials and activities were adapted in any way, student participation, reactions, and questions, and issues that arose during the class.

Table 2: Summary of Data Sources

Data Source	*SM*	*CS (Bio)*	*CS (Bio Tech)*	*CE (Env Sci)*	*CE (Chem)*	*FF*
Pre/Post Test	X	X	X	X	X	X
Student Aha/Confusion Cards		X		X		X
Pre/Post Survey		X	X	X	X	
Teacher Reflections / Debrief	X	X	X	X	X	X
Researcher Observations		X	X	X	X	X

Procedure

Research team members coordinated with participating teachers to facilitate co-teaching (when requested) and scheduling for classroom observation. Each teacher was provided with an evaluation packet that contained instructions, the pretest and posttest for the unit(s) that the teacher planned to implement, the presurvey and postsurvey to assess student attitudes toward science, and a teacher reflection sheet. Teachers were told to let students know that it is okay if they don't know the answers on the tests—we just want to see what they know and what they learned. We also recommended that the teachers frame the unit presentation as both a learning opportunity and as a way for the students to help us improve the curriculum materials.

Data Analysis

Test Scoring

Rubrics for each pre/post test were developed when the tests were created (prior to any classroom implementations). Two researchers were assigned to score tests from each unit. All completed tests for a given unit were graded together regardless of class (implementation), but scorers were not blind to pretest versus posttest. Twenty percent of the tests from each unit were randomly selected to be scored by both researchers, with the restriction that only posttests were double scored because they provided much more variation—most pretests received a score of (or near) zero because most students had not been exposed to nanoscience concepts and applications prior to intervention.

Posttests to be double scored were divided into three sets labeled DS-1, DS-2, and DS-3, respectively. Set DS-1 and DS-2 were used for two cycles of calibration. Set DS-3 was used to check for drift halfway through the scoring process. The remaining tests were randomly divided for single-rater scoring. In all cases, researchers scored the sets independently and then compared and reconciled their scores. Inter-rater agreements for each double scored set and unit are shown in Table 3. Agreement was good (over 80%) on the critical DS-2 and DS-3 sets for all units.

Table 3: Percentage Agreement for Raters by Unit				
Unit	*Set 1 (DS-1)*	*Set 2 (DS-2)*	*Set 3 (DS-3)*	*Total Agreement*
Size Matters	87%	83%	80%	83%
Clear Sunscreen	75%	86%	80%	80%
Clean Energy	89%	89%	96%	91%
Fine Filters	83%	83%	94%	87%

Statistical Analysis

Changes in scores from the pretest to posttest for each implementation (and pre and post attitude survey, where applicable) were verified for normality and evaluated for significance using two-tailed paired sample t-tests, with $p < .05$ as the criteria for significance. Cohen's d was calculated as a measure of effect size. For the surveys, the pooled standard deviation was used, but for the tests, the standard deviation of only the posttest scores was used since the pretest scores had very little variance and use of a standard deviation that included this data in the calculation would lead to an inflated effect size.

To better understand in what areas students were making improvements, when significant pre- to post-test differences were found we compared the changes seen on individual questions. Because the questions had a limited number of possible scores, this data could not be treated as continuous, and significance was evaluated using the non-parametric Wilcoxon test. The asymptotic assumption was used except when $N < 16$, in which case the exact method was used. The alpha level was adjusted for multiple tests using a Bonfiori correction. When significant gains were found, the average percentage gain (out of total possible points) and the percentage of students who showed some gain were calculated.

Qualitative Analysis

Students' written answers on the pretests and posttests were examined in depth to look for trends in the kinds of ideas students were able to grasp and those they had difficulties with. For each question on each unit pre/posttest, student answers were groups into content-based themes and the number of answers reflecting each theme was tallied. Themes and associated tallies are reported and discussed with respect to the ideal answers and related scientific concepts.

A similar strategy was employed for the student confusion and aha cards. Student questions and ideas from these cards were compiled by class and sorted into categories with redundant ideas condensed and tallied. The full list of student questions and ideas from the Clear Sunscreen, Clean Energy, and Fine Filters units are listed in Appendices A-F. Most ideas or questions were unique, but a few were reported repeatedly; in these cases, the number of students who mentioned the idea or question was reported with the item. Ideas mentioned by 5 or more students are highlighted in bold.

RESULTS & DISCUSSION

Student Understanding of Nano-Related Concepts

As shown in Table 4, students made significant gains with large effects sizes from pretest to posttest for all implementations. The specific results of each unit are discussed in detail below.

Table 4: Mean (SD) of Test Scores and Gains for All Implementations

Nano Unit	*Class*	*Grade*	*Duration*	*N*	*Max Value*	*Pre-test*	*Post-test*	*Gain*	*t*	*Effect Size*
SM	Chemistry	10th	2 days	36	20	2.25 (1.87)	8.64 (3.55)	6.39 (3.27)	11.19**	1.80
CS	Biology	9th	4 days	19	20	0.87 (0.98)	11.18 (3.75)	10.32 (3.75)	12.00**	2.75
CS	Biotech	11th/12th	1 day	35	20	0.89 (1.15)	11.33 (2.95)	10.44 (2.74)	22.56**	3.54
CE	Environmental Science	10th	5 days	40	12	0.15 (0.61)	4.25 (2.84)	4.10 (2.66)	9.55**	1.44
CE	Chemistry	10th/11th	3 days	13	12	0.00 (0.00)	3.69 (1.32)	3.69 (1.32)	10.12**	2.81
FF	Environmental Science	10th	4 days	40	20	4.70 (2.67)	13.70 (5.08)	9.00 (4.78)	11.92**	1.77

** $p < .001$

Size Matters

The results of the pretest indicated that with two exceptions, the topic of the unit was entirely new to students (see Table 5). Students did show a low level awareness that applications of nanoscience were being used in society (question 6) and a surprisingly high level of knowledge about how “big” a nanometer was (question 1). A follow-up interview with the implementing teacher revealed that due to her involvement with the project, she had in introduced the topic of the size of a nanometer with her students in a previous unit on general concepts of size and scale. Half of the students provided an example of a nanoscience applications; most of these referred to potential (but non-specific) medical use (e.g., “health cures”).

After 2 days of instruction focused on the topic, significant overall gains from pretest to the posttest were found (see Table 4). Effect size was large (d=1.8), but the average posttest score was only 8.64 out of 20. While the lecture and discussion did have an effect, clearly there is still much room for improvement.

Table 5: Mean Test Question Scores and Gains for a Two-Day Size Matters Implementation in a Chemistry Class (N=36)

Question	*Topic*	*Max Value*	*Pre-test*	*Post-test*	*Gain*	*z*	*Av. Gain (%)*	*% of students w/ gain*
1	How big is a nanometer?	4	1.47	2.42	0.94	3.16[a]	24%	58%
2	What properties change?	4	0.11	2.19	2.08	4.92[a]	52%	86%
3	Why do properties change?	4	0.14	0.92	0.78	3.90[a]	19%	56%
4	How do we "see" at the nanoscale?	2	0.06	0.44	0.39	3.50[a]	19%	36%
5	Explain a tool for "seeing":	3	0.08	0.92	0.83	3.80[a]	28%	50%
6	Describe two applications:	3	0.39	1.75	1.36	4.55[a]	45%	81%

[a] $p < .008$

Interestingly, while all questions showed a significant gain, there were great discrepancies between the gains achieved on different questions (see Table 5). The largest improvements both in terms of average percent gain and the percentage of students who showed some gain were seen for the questions that asked students to name properties that differ at the nanoscale (question 2) and potential useful applications of nanoscience (question 6). These were both very concrete questions asking students about physically observable qualities or objects. In contrast to students' strong improvement in being able to *name* and give examples of properties that change at the nanoscale (question 2), students showed much less improvement in their ability to explain *why* these properties were different (question 3).

With regards to why certain properties change, student answers on the posttest highlight common confusion in two particular areas: how light interacts with matter and the role of the relative dominance of forces at the nanoscale. Many students wrote about both of these ideas, but incorrectly. For example, regarding dominance of forces, answers like "The laws of gravity do not apply to nanoscience" and "Normal physics does not apply to small things" suggest that students believe that forces are discrete and "shut off" at a certain point, rather than being continuous and relative (e.g., at the nanoscale, electromagnetic forces have more effect than gravitational forces on the attraction between objects). We note that a student reading and lab activities that examined the causes of size-dependent properties in more detail were not used by the teacher in this implementation.

While students showed difficulty explaining why properties at the nanoscale were different, their teacher reported that students did not expression any confusion about the fact that properties at the nanoscale can be different, suggesting that students found the idea of changing properties unproblematic. This is concerning, since traditional K-12 science instruction presents characteristic properties as constant for a given substance, and in students' macro-scale world experiences (e.g., studying a pure sample of the substance in quantities big enough to measure under normal laboratory conditions), properties of matter are constant. The lack of concern that these "constants" can change radically at the nanoscale may indicate that the students don't fully understand the notion of properties to begin with.

Students also had difficulties on the topic of tools for seeing at the nanoscale. The questions asking students what it means to "see" at the nanoscale (question 4) and to describe one technology for seeing at the nanoscale (question 5) showed small gains from pretest to posttest, although the gains were still significant. Before the unit, most students thought that seeing at the nanoscale just meant using very strong light microscopes. Afterwards, most students understood that this is not true, although it is not clear that they understood why. Most students recognized that "seeing" at the nanoscale required some "other" sort of device, mentioning that electrons were used instead of light, or giving the name of other equipment used for this purpose (e.g., "scanning electron and probe microscopes"). However, only two students attempted to describe how these devices might work, and neither explanation indicated why a different kind of microscope was needed (i.e., because nanoscale particles are smaller than a wavelength of light). We note that a hands-on activity specifically designed to give students the experience of "seeing" without using their eyes was not used by the teacher in this implementation.

As mentioned earlier, the teacher had included some instruction on the topic of size and scale at the nanoscale before the implementation. Notwithstanding this, the gains were surprisingly low on question 1, which asked students to name a nanoscale object, one smaller, and one bigger but still not visible to the naked eye. Before the unit, most students knew how big a nanometer was compared to a meter, but only 3 students gave examples of a nanosized object that was remotely near nanosized, and about a third gave accurate examples of objects that were smaller or larger. After the unit, all students knew how big nanometer was, half were able to give examples of nanosized objects, two-thirds gave examples of smaller objects (virtually all of these smaller examples were accurate), and virtually all gave accurate examples of larger objects. Rather than giving an example of a nanosized object, students frequently repeated that 10 hydrogen atoms lined up was a nanometer. Again, however, we note that a hands-on activity specifically designed to give students hands-on experience with size relationships was not used by the teacher in this implementation.

Finally, virtually all students were able to answer the questions on nanoscience applications on the posttest (compared to half on the pretest), and their answers were far more specific. Most answers referred to the applications that were directly discussed in the classroom instruction, but only about half elaborated on possible effects of the application on society. Still, most students clearly understood specific applications of nanotechnology in more detail than they did initially.

Summary

Overall these results suggest that a short lesson about nanoscale science—particularly one that is delivered without hands-on experiences or lab activities—is insufficient for most students to produce clear conceptual understandings about why nanosized objects may have different properties than bulk-sized objects of the same substance and why different kinds of microscopes (i.e. that use a mechanism other than light) are needed to "see" at the nanoscale.

Clear Sunscreen

The results of the pretest indicated that the topic of the unit was entirely new to students in both the 9th grade biology and 11th/12th grade biotechnology classes (see Table 4). After the implementations, significant overall gains from pretest to the posttest were found for both biology and biotechnology classes (see Table 4). Interestingly, after the four-day implementation including hands-on activities and labs, the 9th grade biology students were able to achieve posttest scores equivalent to those achieved by 11th/12th biotechnology students who received a one-day condensed presentation of the content (t_{52}=.156, p=.877). Effect size was larger for the biotechnology class (d=3.54) than the biology class (d=2.75) due to a smaller variance in posttest scores. The percent of students who showed some gain on each question was uniformly high across both classes (see Tables 6 & 7), but average posttest scores of 10.32 and 10.44 out of 20 indicate that there is still substantial room for improvement.

Table 6: Mean Test Question Scores and Gains for a Four-Day Clear Sunscreen Implementation in a Biology Class(N=19)

Question	*Topic*	*Max Value*	*Pre-test*	*Posttest*	*Av. Gain*	*z*	*Av. Gain (%)*	*% of students w/ gain*
1a	Chemical structure	3	0.18	1.42	1.24	3.54^b	41%	84%
1b	Kinds of light blocked	3	0.21	1.42	1.21	3.65^b	40%	89%
1c	Way light is blocked	3	0.13	1.92	1.79	3.55^b	60%	84%
1d	Appearance on the skin	3	0.21	2.16	1.95	3.85^b	65%	100%
2	Benefits and drawbacks	2	0.03	1.45	1.42	3.82^b	71%	95%
3	What determines color	4	0.00	1.39	1.39	3.78^b	35%	95%
4	How know if nano sunscreen	2	0.11	1.42	1.32	3.68^b	66%	89%

^{b} p < .007

In terms of the understanding of specific topics / concepts within the unit, a similar pattern was observed across both classes. Students showed the greatest average gain on questions that asked about concrete properties that related to their concerns as consumers; specifically, the questions that asked about how sunscreens appear (Q1d), the benefits and drawbacks of nano sunscreens (Q2) and how to know if a sunscreen has nano ingredients in it (Q4). A similar focus on issues related to students' role as consumers was seen in the statements / questions handed in on the biology students' "confusion" and "wow" cards. The qualitative analysis revealed that when students did not do well on test questions related to these issues, it was generally because they only answered part of the question, or their answer was incomplete. No particular misconceptions were observed in the answers given to these questions.

Table 7: Mean Test Question Scores and Gains for a One-Day Clear Sunscreen Implementation in a Biotechnology Class (N=35)

Question	*Topic*	*Max Value*	*Pre-test*	*Posttest*	*Av. Gain*	*z*	*Av. Gain (%)*	*% of students w/ gain*
1a	Chemical structure	3	0.13	1.54	1.41	4.88[b]	47%	91%
1b	Kinds of light blocked	3	0.17	1.59	1.41	4.98[b]	47%	91%
1c	Way light is blocked	3	0.11	1.66	1.54	4.97[b]	51%	91%
1d	Appearance on the skin	3	0.30	2.50	2.20	5.13[b]	73%	97%
2	Benefits and drawbacks	2	0.10	1.26	1.16	5.23[b]	58%	94%
3	What determines color	4	0.00	1.40	1.40	5.20[b]	35%	97%
4	How know if nano sunscreen	2	0.07	1.39	1.31	4.96[b]	66%	89%

[b] $p < .007$

In contrast, students often showed difficulties on questions that related to mechanisms of action based on conceptual models. In particular, the question that asked students to explain what determines if a sunscreen appears white or clear on the skin (Q3) caused great difficulties for students as indicated by a low average percent gain in both classes. Questions about the chemical structure of sunscreen ingredients (Q1a) and how they block light from reaching the skin (Qs 1b & 1c) showed moderate average gains for both classes, although the biology students did somewhat better on the blocking mechanism question (1c) than they did on the kinds of light blocked question (1b). In contrast to the more concrete question, the qualitative analysis of these questions revealed several conceptual areas of student confusion and misunderstanding. In the following sections, we review the primary misunderstandings of relevant scientific concepts exhibited in student test answers.

Molecules versus Ionic Compounds

A key concept in the Clear Sunscreen Unit was the difference between molecules and ionic compounds and the ideas that nano versions of ionic compounds retain the same chemical properties but have different physical properties. This was a concept that we saw students have particular difficulty with in the pilot testing of this unit—many thought that a smaller size version of a compound had the same number of atoms, with the individual atoms being smaller in size—and one which was specifically targeted for elaboration and clarification in the unit revisions following the pilot.

While the idea of "smaller atoms" was not prevalent in student work in this evaluation, the differences between molecular and ionic compounds continued to be a problem for students. This was most notably evident in the posttest answers to question 1a. When asked about the differences in chemical structure between nano and organic ingredients, only 9 students (3 bio, 6 biotech) correctly noted that organic ingredients exist as molecules while nano ingredients are ionic clusters. Four students (1 bio, 3 biotech) referred to these concepts but confounded them, referring to the notion of "clumps of molecules" or indicating that nano ingredients had a "different number of molecules" than organic ingredients. The majority of the students did not refer to these key ideas.

When asked about the differences in chemical structure between nano and traditional *in*organic ingredients, 21 students (4 bio, 17 biotech) correctly indicated that nano ingredients were smaller clusters of the same inorganic ingredients while 12 students (4 bio, 8 biotech) noted that nano ingredients were different from traditional inorganic ingredients simply in that they were smaller without explicitly noting the similarity in chemical structure. It was often not possible to infer from student phrasing of answers if they correctly understood what "smaller cluster" meant in a physical sense—for example, one (biotech) student said "smaller zinc, titanium, and oxygen bond together." It is unclear if they are correctly indicating that a smaller *number* of zinc, titanium and oxygen bond together, or if they imagine that *smaller size* zinc, titanium and oxygen bond together—which would indicate the same problem we saw in the pilot. In addition, one (biotech) student said "the molecule is made very small," showing that there was some confusion between the idea of molecules (which are fixed in size) and ionic clusters (which can vary in size).

Confusions between molecules and ionic compounds were also seen in question 3. While a large proportion of the students (42) correctly indicated that "size" of the active sunscreen ingredients was the primary determinant of a sunscreen's appearance (15 bio, 27 biotech), only 24 students (9 bio, 15 biotech) correctly referred to the size of the sunscreen "particles," while 10 (2 bio, 8 biotech) referred to size of the sunscreen "molecules" and 8 (4 bio, 4 biotech) just referred to size in general. While it is true that active sunscreen ingredients can exist as molecules (e.g., organic ingredients), the size of all these different molecules is so small that it does not affect the appearance of the sunscreen—they all appear clear. In contrast, the size of the inorganic cluster does vary to a great enough degree so as to affect the appearance of a sunscreen. Only two biotech students correctly discussed in detail the relationship between particle size and light wavelength in terms of determining if scattering would occur.

We had expected that the $11^{th}/12^{th}$ grade biotechnology students would have fewer difficulties with the distinctions between molecules and ionic compounds than the 9^{th} grade biology students, since they had taken chemistry previously. However, the evidence showed the same kinds of confusions exhibited by the biology students. This seems to be a core chemistry concept that standard instruction does not sufficiently address. In addition, it seems to be a particularly challenging concept area for students since it was specifically addressed in the unit materials, yet many students emerged from the unit with confusions.

Size & Scale

Although not the primary focus of the unit, concepts of size and scale did come into play in the Clear Sunscreen unit with respect to understanding the relative size of nano and organic sunscreen ingredients. For example, in Question 1a, students were asked about the differences between the structure of "nano" sunscreen ingredients and traditional organic and inorganic ones. While the question targeted the structural differences between molecules and ionic compounds, several students focused their answers on issues of size. Six students (2 bio, 4 biotech) indicated that nano were similar to organic in that they were both small and 8 students (4 bio, 4 biotech) thought that the difference between the ingredients was that nano ingredients were smaller than organic molecules. No students indicated the correct size relationship of organic sunscreen molecules being much smaller than the nano inorganic active ingredient. This evidence suggests that students have a weak sense of the size and scale of chemical substances.

UVA/UVB as Reified Entities

Another key idea in the Clear Sunscreen unit was the notion that different kinds of sunscreen ingredients (organic versus inorganic) have different absorption patterns; specifically, organic ingredients have relatively narrow, peaked absorption spectra while inorganic ingredients absorb all UV light up to a cutoff wavelength, producing "cliff-shaped" spectra. Although the unit was taught from this perspective—focusing on the scientific concepts underlying the notions of "UV protection," students seemed to approach the issues from a consumer perspective—focusing on the kind of protection provided as the primary phenomenon without attention to the underlying mechanisms of how this protection was provided. Furthermore, despite a discussion about the notion of "UVA" and "UVB" as scientist-imposed ranges along a continuum, students often treated them as singular entities that were blocked (or not) in a binary fashion. While this fits with the language used in popular media, we had expected that direct instruction targeting this issue would have more of an effect.

The notion of UVA and UVB as reified entities was also seen in student responses to a question that asked about the different kinds of light blocked by nano and organic sunscreen ingredients (Q1b). For this question, 20 students (8 bio, 12 biotech) indicated that nano ingredients block both UVA and UVB light in contrast to organic ingredients, which only block UVB light. While it is true that nano ingredients block both kinds of light, there are organic ingredients that can block UVA; the key difference is actually related to the absorption pattern. Because of the absorption mechanism, organic ingredients can only block a narrow range of wavelengths (UVA or UVB) while inorganic ingredients (including nano ingredients) can block the whole UV spectrum. Only 12 students (4 bio, 8 biotech) mentioned this. On the question that asked about the different kinds of light blocked by nano and traditional inorganic sunscreen ingredients, 22 students (8 bio, 14 biotech) correctly noted that both nano and traditional inorganic ingredients block both UVA and UVB light, however only four of these students (1 bio, 3 biotech) specifically noted that they blocked a wide range of wavelengths. In addition two (biotech) students noted that both blocked UVA light (but did not mention UVB) and one (bio) student noted that they both blocked UVB (but did not mention UVA). Four students (1 bio, 3 biotech) noted that they blocked the same range of frequencies of light, but did not specify what this range was. Three students (1 bio, 2 biotech) noted that the both block UV light and one student from each group simply noted that they blocked the same kind of light.

A focus on distinction between UVA / UVB was also apparent in students "aha" and "confusion" cards. The most common question submitted by students on their "question" cards was about the differences between UVA and UVB light. Students were also curious about the meaning and importance of SPF. It seems that although students may have encountered these terms in their experiences as sunscreen consumers, they did not feel that they understood what they were about. This interest was also seen in the large number of "wow" statements that related to the differences between UVA and UVB light. The "wow" statements also showed that students were excited to learn about UVC, since it was a kind of UV light they had not heard of before. Several students were concerned about environmental issues related to UVC light (such as the depletion of the ozone layer) that might allow it to reach the earth at some point.

One related confusion that was noted in several student comments was the idea that sunscreens "contain" UVA / UVB. A similar idea came out during one of the class discussions. We do not know why students thought this; one possibility is that the language used on sunscreen labels that refers to sunscreens containing "UVA / UVB protection" may be interpreted by some students as referring to two kinds of protection as opposed to protection from two kinds of light. The way several students reified "UVA" and "UVB" as something that could be put into sunscreens is parallel to their test-exhibited notions of UVA and UVB as qualitative types of light, instead of as labels for a range of wavelengths.

Students were specifically concerned with the concepts of UVA and UVB light on a practical level related to how to choose a sunscreen that provides good protection. While a large number of students made wow statements related to the protection that sunscreen provides, only a small portion of these focused on the mechanism of how sunscreens protect us as opposed to more superficial issues related to different levels/kinds of protection. Students seemed especially fascinated by looking at the ingredient labels of sunscreen products they use and made many comments related to this topic. Several question and aha cards addressed the relationship between the different ingredients (including their chemical make-up).

Different Kinds of Interactions with Different Kinds of Light

Another area of confusion for many students was distinguishing between the how sunscreens interact with UV and visible light and clearly identifying the mechanisms for each. This does not seem to be an issue of a conceptual difficulty as much as a more general confusion of information. For example, in the question that asked about the kinds of light that are blocked by nano versus organic-sunscreens (Q1b), the intent was to focus on UV light, but 6 students discussed the interactions between the sunscreens and visible light. In talking about these, 3 students (2 bio, 1 biotech) correctly stated that a difference between the two kinds of ingredients is that nano ingredients do not scatter/reflect visible light, while 3 (2 bio, 1 biotech) incorrectly stated that both nano and inorganic ingredients block visible light. In addition some conceptual confusions about this process were revealed by the following statements: "it reflects skin color light but on the smaller scale" and "the nano particles scatter visible light only absorbing UVB/UVA while current ingredients scatter light." Of those who answered the question as intended, 25 students (9 bio, 16 biotech) correctly stated that both organic and nano ingredients block via absorption, but 3 of the biotech students incorrectly indicated that they also reflect/scatter light. An additional 4 (1 bio, 3 biotech) students indicated reflection/scattering as the only blocking mechanism and 1 (biotech) student simply said that both "dissipate" the light.

In comparing nano with traditional *in*organic ingredients, 21 students (9 bio, 12 biotech) correctly indicated that both nano and traditional inorganic ingredients block via absorption, but one of these students (biotech) indicated that "mild scattering" was also involved. An additional (biotech) student indicated that nano ingredients block via absorption while traditional inorganics block via reflection. 3 students (2 bio, 1 biotech) simply indicated that the blocking mechanism was the same without further elaboration. 8 students (2 bio, 6 biotech) incorrectly identified scattering or reflection as the UV blocking mechanism. Together, these comments show that many students were unclear about the different mechanisms by which light interacts with sunscreen.

What Makes Things Appear Certain Colors

In discussing what determines the appearance of a sunscreen (Q3), after the unit most students were clear that that the size of the active ingredients was the key factor, but many students' explanations did not go beyond this level, which explains why a large percentage of students showed gain on this question but there was a low average percent gain. Of the students who did go into more depth on the mechanism, most explained quite well the role of scattering in making something appear white, but few seemed to understand correctly how making the nanoparticles too small to scatter light allowed the skin to appear skin-colored.

Only one student in the biology class attempted an explanation of this, and the explanation did correctly note that nanoparticles were small enough to let the visible light pass through and that the skin would only reflect red/orange/yellow color of visible light. In the biotechnology class, many more explanations were attempted, but most revealed confusions. For example, 5 biotech students (incorrectly) focused on whether or not the sunscreen would absorb visible light, and 3 of these stated that if visible light was absorbed, the sunscreen would appear clear. 7 students implied that when sunscreen appeared skin colored, it was because it was only absorbing some (as opposed to all) of the visible spectrum, for example, "[it appear clear] if the sunscreen reflects or absorbs green/blue light" and "sunscreen is clear when the white visible light is absorbed." Two students did correctly describe how nanoparticles do not scatter visible light, letting through to the skin where it can be partially absorbed by the skin.

Summary

Taken as a whole, these results indicate some improvement in students' understanding of concepts related to clear (nano) sunscreen, highlight key areas of confusion, and indicate places where a lack of foundation was problematic. Perhaps the most interesting finding was the similarity in outcomes between a 4-day implementation in a standard biology class and a 1-day implementation in an advanced biotechnology class. This suggests that some combination of the additional time devoted to the topic and inclusion of hands-on activities helped compensate for the biology students' lack of background knowledge.

Clean Energy

Pretest scores on the Clean Energy implementation in two classrooms indicated that students had little to no understanding of what nano-based, dye-sensitized solar cells are, how they work, or what their advantages are in addressing global energy issues (Table 4). These findings are not surprising given that students most likely had limited or no exposure to this type of solar cell prior to the Clean Energy unit.

The follow-up analysis for both Clean Energy implementations showed significant gain scores for all of the questions in Teacher M's class and one question in Teacher J's class (Tables 8 & 9). The biggest average percent gain and percentage of students with some gain was highest for Q1 and Q3. Q1 focused on advantages of dye-sensitized solar cells. This question didn't require a deep understanding of the science behind dye-sensitized solar cells, but rather focused on the technical advantages that these types of solar cells have over more traditional silicon-based solar cells. Q3 focused on how dye-sensitized solar cells work. Full credit on this question required description of the mechanisms underlying dye-sensitized solar cells. Students were prompted to show their understanding through text explanation as well as annotated diagrams.

Table 8: Mean Test Question Scores and Gains for a Five-Day Clean Energy Implementation in an Environment Science Class (N=40)

Question	*Topic*	*Max Value*	*Pre-test*	*Post-test*	*Gain*	*Z*	*Av. Gain (%)*	*% of students w/ gain*
1	Advantages of nano solar cells	2	0.10	1.15	1.05	4.83[c]	53%	75%
2	Why nano TiO2?	2	0.03	0.63	0.60	3.69[c]	30%	45%
3	How do nano solar cells work?	6	0.00	1.93	1.93	4.48[c]	32%	65%
4	What is the role of the dye?	2	0.03	0.55	0.53	4.19[c]	26%	48%

[c] $p < .013$

Table 9: Mean Test Question Scores and Gains for a Three-Day Clean Energy Implementation in a Chemistry Class (N=13)

Question	*Topic*	*Max Value*	*Pre-test*	*Post-test*	*Gain*	*Z*	*Av. Gain (%)*	*% of students w/ gain*
1	Advantages of nano solar cells	2	0.00	0.62	0.62	2.53		
2	Why nano TiO2?	2	0.00	0.31	0.31	2.00		
3	How do nano solar cells work?	6	0.00	2.23	2.23	3.24[c]	37%	100%
4	What is the role of the dye?	2	0.00	0.54	0.54	2.33		

[c] $p < .013$

Closer examination of student answers to Q1 and Q3 revealed that they generally understood surface-level aspects of dye-sensitized solar cells. For example, on Q1, students were often able to list advantages of using dye-sensitized solar cells over other energy technologies (e.g. silicon-based solar cells) or sources (e.g. fossil fuels.) For Q3, students were often able to describe particular parts of the cells, but had difficulty explaining how the different parts of the cell related functionally. This was reflected in the high percentage of students who showed some gain on this question, but a low average percent gain. They were able to draw and label a number of cell parts, but frequently left out any explanation of how these parts interacted with each other. While students were able to provide some explanation of how dye-sensitized solar cells worked, their drawings, although often accurate from a macro-level standpoint, rarely pointed to or explained the mechanisms underlying the energy conversion and the electron transfer in the cell. Some students' drawings showed a resemblance to the Clean Energy flash animation they saw in class of how a dye-sensitized solar cell works (which included the electron holes, electrons traveling, and the labels for dye and TiO_2). However, few of the depictions were accurate. Only ten out of 53 students created good diagrams listing the various parts of the cell. Out of the 10 students that drew good reproductions, 7 had no explanations associated with them. The three students who did have explanations had very good ones, suggesting that they reproducing the diagram accurately may require conceptual understanding.

Students fared less well on Q2 and Q4. These questions asked students to explain specific aspects of dye-sensitized solar cells, particularly the science underlying the cell's function. Q2 focused on the importance of nanosized titanium dioxide particles in the functioning of dye-sensitized solar cells, while Q4 focused on the role of the dye in these cells. Compared to Q1 and Q3, these questions required a deeper understanding of the "why" of dye-sensitized solar cells as opposed to simply the "what." Students showed very limited and fragmented understanding of these more in-depth aspects of dye-sensitized solar cells, such as the functioning of nanosized titanium dioxide particles and dye molecules in the cells. Student responses for Q2 displayed general understanding that nanosized $Ti0_2$ was important to the generation of electricity in the solar cell, but suggested only partial understanding of why the $Ti0_2$ had to be present in nano–sized clusters. For example, when asked why the $Ti0_2$ in the cell has to be "very small, aka 'nano'," 14 out of 55 students mentioned that "lights needs to shine through" the TiO_2. While nanosized TiO_2 does allow light to more readily pass through and reach the dye molecules, in many cases, students didn't explain why it was important for the light to shine through: to effectively allow photons to reach the dye molecules, which in turn release electrons. (On the student "confusion" cards several students mentioned confusion around light absorption or electron transitions, perhaps warranting greater focus by the implementing teacher.) Other reasons for the importance of nanosized TiO_2—such as "more surface" area (3 students), and "generates more electricity" (3 students)—accurately reflect the impact of nanosized $Ti0_2$ on the functioning of the solar cell. However, these responses are incomplete because they do not include a discussion of how the light causes electrons to be released form the dye molecules, suggesting a limited understanding of the underlying mechanism.

For example, no students discussed the important idea that the dye molecules are attached to the $Ti0_2$, and that by using very thin layers of $Ti0_2$, a greater surface area of dye-molecules is created, effectively increasing the target upon which photons from the sun could strike. It is important that the $Ti0_2$ be nanosized, otherwise it would block the light and no light would reach the dye molecules. Students did hint at the idea of nanosized $Ti0_2$ particles creating “more surface” area and allowing a higher density of dye molecules, thus increasing absorption of photons. Many students provided a simplistic response to this question, one that was either a misconception (e.g. “contains lots of energy,” “they need to be microscopic”) or a one-dimensional hint at a richer, more involved mechanism (e.g. “more surface,” “a lot can fit,” “help transfer energy,” “allows light to shine through.”) Students appeared to develop a partial understanding related to this question, but had significant holes in their understanding.

Students provided a wide range of answers for Q4, regarding the role of the dye in dye-sensitized solar cells: over 17 unique answers were given. Common answers included “absorb sunlight” (12 out of 55 students) and “release/generate electricity” (11 out of 55 students). While these answers are technically correct, only two students mentioned the more complete answer that the dye “absorbs photons.” Remaining responses to this question were unique to one or two individuals and highlight a range of incorrect ideas, such as “conduct heat from the sun” or to “add color” or to “attract sunlight.” Seven students did display understanding that dye-sensitized solar cells use light energy from the sun, but only a few of these students (5 out of 25) said that the dye-sensitized solar cell converts sunlight into electrical energy. Only 3 students provided more complete details about the process—that photons excite the electrons, which jump out of the dye and create “electricity.” Again, with only 3 out of 53 students being able to describe a core function of dye-sensitized solar cells, there is substantial room for improvement.

Summary

Overall, we saw gains across the tests as a whole (Tables 8 & 9), suggesting that students did develop a richer understanding of clean energy concepts. Students were exposed to many energy-related ideas for the first time, and their aha/wow cards suggest that many students across both classrooms that were intrigued by the high rate of oil consumption in the U.S. (27 students) and that energy is the top issue facing the world (14 students). As the test questions highlight, particularly Q2, Q3, and Q4, there were many new concepts introduced in the unit and understanding the underlying science was far from trivial. Students were expected to understand not only what nanoscale particles were, but also how these particles needed to be specifically arranged in the cell and how they successfully convert solar energy into electrical energy. The range of inaccurate or surface-level responses across the questions suggest that the underlying mechanisms were difficult for students to grasp in the limited amount of time they participated in the Clean Energy unit (three days for classroom 1 and five day for classroom 2). In addition, the concepts that the Clean Energy unit introduced often relied on prior student understanding of basic molecular physics concepts such as what electrons are, how they can be released, and how they move.

Fine Filters

Gain scores and effect sizes for the Fine Filters implementation (Table 4) show significant gains from pretest to posttest. Although the gains were considerable (and the largest of any of the four units), the moderate average posttest scores (13.7 out of 20 points) indicates that there is still room for improvement in mastery of the Fine Filters learning goals.

Table 10 provides a question-level breakdown of the assessment. Overall, the pretests included many blank or very surface-level responses. In some cases, the responses indicated that students lack a strong grasp of the size or scale of very small or nanosized objects. For example, when asked to name two benefits to using nanofilters, one student responded, "They can get out tiny dangerous atom sized bacteria." At pretest, several students provided responses that reflected basic misunderstandings about chemicals in solution such as, "lead is a solid so it wouldn't be able to get through a nm filter," "[Lead] is denser than the nanofilter so can't go through," and "salt bonds with water so it can't be filtered out."

Table 10: Mean Test Question Scores and Gains for a Four-Day Fine Filters Implementation in an Environmental Science Class (N=40)

Question	*Topic*	*Max Value*	*Pre-test*	*Post-test*	*Gain*	*z*	*Av. Gain (%)*	*% of students w/ gain*
1a	Nanomembrane filter bacteria?	3	1.25	2.03	0.78	3.86[a]	26%	55%
1b	Nanomembrane filter lead?	3	0.85	2.05	1.20	4.60[a]	40%	75%
1c	Nanomembrane filter salt?	3	0.78	1.80	1.03	3.64[a]	34%	68%
1d	Nanomembrane filter sand?	3	1.15	1.93	0.78	3.94[a]	26%	60%
2	Benefits of nanomembranes	2	0.28	1.23	0.95	4.50[a]	48%	65%
3	How nanofilters differ	6	0.40	4.68	4.28	5.30[a]	71%	88%

[a] $p < .008$

Posttest answers tended to be more specific that those on the pre-test although they varied in the level of accuracy and the detail. At posttest, many students included the concept of filtering monovalent or bivalent ions in their answers, an idea none had mentioned on the pre-test. Over half the students wrote about the idea of using the least expensive filter that could filter out the unwanted substances(s), and a majority of students mentioned the idea of comparing the cost between different sizes of filters.

Q1a had the lowest percentage of students demonstrating a significant gain score and one of the lowest average percent gains. This question focused on bacteria filtering and the effectiveness of nanomembranes to do so. Qualitative analysis of this question showed that students were confused on the concepts of size and filtration. The majority of students provided responses to this question, but these responses were often an unclear application of ideas from this unit. For example, when asked why nanofilters could filter bacteria, 10 students referred to the size of the filter relative to the size of the bacteria as an appropriate reason, but it was often not clear whether students thought the bacteria was larger or smaller than the pore size of the nanofilter.

Nanomembranes' ability to filter sand (Q1d) was also not widely understood by students. Although nearly all students indicated that nanofilters *could* filter sand, explanations given for why a nanofilter would not be the best choice to filter sand were varied, and sometime unrelated to core filtration principles, for example "because it is solid" or "because it is heavier." Although the Fine Filters unit emphasized appropriate selection of filter type based on pore size, cost, and fouling potential, on the posttest only 60% of the students accurately indicated that there are better methods for filtering sand than using nanofilters.

Students showed particularly strong pretest-posttest improvement on Q3, "Describe three ways in which nanofilters can operate differently than traditional filters to purify water." At pretest, half of the student left this question blank, while the other half provided very general statements such as "able to filter more stuff" than other filters, "more technology has was put in them," or "they are scientifically proven better." On the posttest, student responses tended to be more focused. Almost all students indicated that new nanofilters could kill bacteria, and most responses accurately conveyed the concept of nanomembrane filters requiring less pressure to operate than other filtration systems. In relation to the topic covered by Q3, classroom observations revealed student-teacher engagement around filter comparison. The teacher posed a pertinent question, reinforced correct student responses aloud in class, and then began with the same question to the students the following day. This technique may have been particularly helpful in student learning, as she was not observed using this technique on other concepts asked on the assessment.

In general, many students used terms such as "charge," "small," "kill bacteria," and "bivalent ions" with various degrees of accuracy, indicating a spectrum of understanding of these terms. Roughly a third of the student used these terms inappropriately. For instance, there was an emphasis within the unit on killing bacteria. A traditional method of killing bacteria by adding chlorine to water was taught, as well as the nontraditional method of embedding toxic substances (to bacteria) within nanomembranes. Many students wrote about killing bacteria and chlorine, but there were several areas of confusion illustrated by students when addressing this concept. One student erroneously wrote, "Chlorine is embedded within the nanomembrane filter" rather than added directly to water. In contrast, the majority of students used the correct terminology when asked to identify mechanisms by which nanofilters worked.

Summary

Overall, students were interested and engaged by clean water scarcity as a global issue and motivated to learn about the topic of water filtration. Academically, students showed the largest gains out of any of the four units; however the results also highlighted several areas of difficulty for students in relation to solution chemistry, including relative size and scale of different objects and the role of charge as a method of separation. Though the teacher taught them some of the fundamentals about the chemistry of water prior to using the unit, students did not appear to be able to these concepts flexibly enough to fully understand how different types of matter dissolve in water, and how and why this makes a difference when using small scale filtration methods. Students did, however, show an increase in their knowledge about the more basic aspects filtration. The teacher indicated that they were proud of their accomplishments of being able to learn about new, exciting, and relevant technology.

Student Attitudes Towards Science

Table 11 shows students survey scores related to their attitudes about science for each unit in which the surveys were administered. The summed six question scale ran from 6 to 30 with a higher score indicating a more positive attitude towards the relevance of science. As shown in Table 11, significant gains on attitudes about science were found for both Clear Sunscreen implementations and one of the two Clean Energy implementations. It is noteworthy that while the effect size was relatively small, a significant change in students' attitudes towards science was found based on only a one-day implementation (of the Clear Sunscreen unit with Biotechnology students).

Table 11: Mean (SD) of Survey Scores and Gains for All Implementations

NanoUnit	*Class*	*Grade*	*Duration*	*N*	*Pre-survey*	*Post-survey*	*Gain*	*t*	*Effect Size*
SM	Chemistry	10th	2 days	-	-	-	-	-	-
CS	Biology	9th	4 days	16	23.13 (2.61)	25.13 (2.02)	2.00 (1.96)	4.14**	0.86
CS	Biotech	11th/12th	1 day	30	25.17 (3.10)	26.33 (2.82)	1.17 (1.71)	3.70**	0.39
CE	Environmental Science	10th	5 days	20	21.10 (3.72)	23.10 (2.46)	2.00 (2.38)	3.23*	0.63
CE	Chemistry	10th/11th	3 days	14	21.86 (3.74)	22.29 (3.67)	0.43 (2.79)	0.54	-
FF	Environmental Science	10th	4 days	-	-	-	-	-	-

* $p < .01$ ** $p < .001$

Follow-up examination of the individual questions showed a significant gain for the question *Much of what I learn in science classes is useful in my everyday life today* in both the 4-day biology and the 1-day biotechnology Clear Sunscreen implementations (Tables 12 & 13) but not for any of the other questions about the relevance of science (Q2-5) or the question on career aspirations (Q6). While the 5-day environmental science implementation showed significant overall gains in attitude from pre- to post-test, no single question met the minimum significance level ($p < .008$). The 3-day implementation of Clean Energy in the chemistry class resulted in no significant gains overall or for any individual questions.

Table 12: Mean Attitude Question Scores and Gains for a Four-Day Clear Sunscreen Implementation in a Biology Class(N=16)

Question	*Topic*	*Pre-test*	*Post-test*	*Gain*	*z*	*% of students w/ gain*
1	What I learn in science classes is useful in my everyday life	3.63	4.50	0.88	3.07[a]	69%
2	Science helps me make decisions that could effect my body	4.63	4.81	0.19	1.34	
3	Science helps me understand more about world-wide problems	3.88	4.13	0.25	1.15	
4	Science can help me make better choices in my life	4.19	4.44	0.25	1.19	
5	Understanding science helps me explain things to others	3.69	4.06	0.38	1.73	
6	I am interested in a career as a scientist or engineer	3.13	3.19	0.06	.58	

[a] $p < .008$

Table 13: Mean Attitude Question Scores and Gains for a One-Day Clear Sunscreen Implementation in a Biotechnology Class (N=30)

Question	*Topic*	*Pre-test*	*Post-test*	*Gain*	*z*	*% of students w/ gain*
1	What I learn in science classes is useful in my everyday life	3.83	4.33	0.50	2.98[a]	47%
2	Science helps me make decisions that could effect my body	4.30	4.60	0.30	1.90	
3	Science helps me understand more about world-wide problems	4.27	4.27	0.00	0.00	
4	Science can help me make better choices in my life	4.20	4.53	0.33	2.35	
5	Understanding science helps me explain things to others	4.27	4.37	0.10	.83	
6	I am interested in a career as a scientist or engineer	4.30	4.23	-0.07	.54	

[a] $p < .008$

Teacher Reflections & Researcher Observations

After completing the unit/lesson, each teacher was asked to reflect on how it went. In particular, they were asked if students seemed to be interested in the lessons, if they seemed to understand the content, and if there were any areas of confusion. Observations of classroom sessions by NanoSense team members were also collected. These observations and reflections are summarized below.

Teacher C

In her reflection on the Size Matters implementation, Teacher C reported that her students "were definitely interested and asked many questions" and that they "understood the concepts as it was very general material." When asked if there were any areas of confusion, she reported, "Honestly, I would say no."

Teacher G

In her reflection on the Clear Sunscreen implementation, Teacher G reported that the activities were easy to weave into other topics, such as the biology of a sunburn, and "students loved the unit." They seemed to understand the content and asked lots of good questions. "The 60-minute period ended too quickly," she said. " The students—all of them!—really enjoyed this initial excursion into nanoscience, and are enthusiastic for more."

Teacher G also reported that she enjoyed and learned from the co-teaching process: "It was really enjoyable for me to work with you to prepare for and implement the lessons. I especially appreciated learning from the "experts" about how best to organize, adapt, and present the nano sunscreen unit to the freshmen. It was also a pleasure seeing how receptive the biotech students were to the higher levels of content…. Thanks to your fine efforts I now have a much better sense for how to implement this unit effectively."

NanoSense team members observed that students seemed genuinely interested and concerned about sunscreen issues. It was apparent that the issues hit home in that student questions were real (e.g., how am I going to get something that protects me?). The kids realized quickly that there was a lot that they didn't know. They were so engaged and there were so many questions that it was difficult to get through all of the materials. In the biology class, the decision was made to skip some of the material, such as talking about wavelength in a quantitative way (wavelength was covered conceptually), and a concluding activity (the pamphlet).

Teacher M

In her reflection on the Clean Energy implementation, Teacher M reported that student interest was really high, partly because it was perfectly fit to her curriculum. Students were intrigued by the real world application, and some were excited. They took pride in the fact that they understood the energy problem, and majority of kids were able to apply the issues to their everyday lives. However, she was less confident that the students understood the electron transfer and the role of the different layers in the nanocrystalline solar cell. She further stated that in many cases, students took ownership of what they could understand, even if they couldn't understand every detail of the science content, and that the majority of kids were able to apply the issues to their everyday lives.

In her reflection on the Fine Filters implementation, Teacher M reported that the students were interested, and because she prepared them well before the unit (e.g., talked about the chemistry of water and details of atomic structure), the students had more background knowledge and were that enabled them to "own" the new information. They enjoyed the labs, and discussions about what they found in the labs were animated. Students had engaging questions and statements, and liked the feeling of being scientists. They understood that nanotechnology is an alternate way to filter things, although they may not have deeply understood how the nanofilter worked. Students who had the least background in atomic structure exhibited more confusion.

Overall, Teacher M reported that it was a “fabulous experience, enriching for me, enriching for my curriculum, and engaging for the students, which is the best part.”

NanoSense team members observed that Teacher M was much more comfortable with the material (for both Clean Energy and Fine Filters) in the implementations described here, compared to the pilot implementations that she did the year before. Teacher M gave very clear directions and focused specifically on the parts of the material she wanted the students to learn. The students were engaged in the lab and seemed to understand clearly what they were doing.

Teacher J

In her reflection on the Clean Energy implementation, Teacher J reported that “most of the students were very engaged” and “asked some good questions.” One of her special education students was “extremely involved” and asked some questions that impressed her. She felt that most of the students understood the content, but there were some misconceptions that occurred with a few of the students. For example, she was less confident that her students understood electron transfer. She felt that her students understood *what* was nano, but had difficulty understanding the role of the different layers and components in the cell.

NanoSense team members Dr. Scharberg and Dr. Rosenquist reported that the students seemed engaged, and the top-10 list of global problems went very well. Some students seemed to get into the ideas of clean (nano) energy and asked good questions, while others seemed distracted or confused. The lab had been prepped well, but some lab equipment had been moved prior to the session so there was a bit of scrambling to find equipment and get it set up while the students were waiting, which resulted in loss of attention by some students.

ANSWERING THE EVALUATION QUESTIONS

Evaluation Question 1: Student Understanding of Nano-Related Concepts

Does learning the NanoSense Curricula increase students' understanding of nano-related concepts?

a. What nano-related concepts did students understand and which ones challenged them?
b. What foundational understandings needed to learn nano-related concepts students have difficulties with?

Overall, our results showed that using NanoSense curricula did increase students’ understanding of some nano-related concepts. This is evidenced by the significant pre- to post-test gains with large effects found for all implementations. Nonetheless, there is clearly room for improvement. Students were still challenged by particular nano-related concepts, and had difficulties with some foundational understandings necessary to fully understand nano-related concepts.

Nano-Related Concepts that Students Understood

Across units, students showed large gains in understanding in two areas: one, what properties of substances differ between bulk and nanosized materials; and two, the need for—and potential benefits and drawbacks of—applications of nanoscience. Students also showed large gains on several unit-specific concepts: in the Clear Sunscreen unit this included understanding how nano (vs. traditional) sunscreens appear on the skin and how to know if a sunscreen contains nano ingredients; in the Fine Filters unit this included what nanofilters can filter (bacteria, lead, salt, sand) and how nanofilters differ from traditional filters. Results for the Clear Energy were less consistent across classes, but some students showed evidence of increased understanding of the advantages of dye-sensitized (nano) solar cells and the different parts of the cells.

Conceptual Difficulties

Students had more difficulty, across all units, understanding why properties differ in terms of the scientific mechanisms that produce the effects, and relating the distinctness of the nanoscale with the continuity of scientific principles. Students were also challenged by several unit-specific concepts, including how light interacts with matter (Clear Sunscreen and Clean Energy), what makes things appear different colors (Clear Sunscreen), size and scale (Size Matters, Fine Filters and Clear Sunscreen), the relative dominance of forces at the nanoscale, and what it means to "see" at the nanoscale (both in Size Matters). Below we discuss in more detail two major themes related to the concepts that students had difficulty with across units.

Students can say what, but not explain why

Based on our results, it appears that students gained an understanding of *what* properties of a substance are different at the nanoscale, but had more difficulty understanding *why* these properties differ in terms of the scientific mechanisms that produce the effects. This was seen in all of the four units. For example, in the Size Matters unit, the largest improvements were seen for the questions that asked students to name properties that differ at the nanoscale and to describe applications of nanotechnology. These were both concrete questions asking students about physically observable qualities or objects. In contrast, when asked to explain *why* these properties differed, they were less able to formulate an appropriate answer.

In the Clear Sunscreen unit, students showed the greatest average gain on questions that asked about concrete properties that related to their concerns as a consumer. In contrast, students had more difficulty on questions that related to conceptual models of mechanisms of action or chemical structure, such as, explaining what determines if sunscreen appeared white or clear on the skin or how sunscreen blocks light. Similarly, for Clean Energy, students were generally able to describe characteristics of dye-sensitized solar cells (e.g. "flexible" and "renewable") and draw several of the elements that construct a nanosolar cell, but they were less able to explain the interactions between the component parts that produced electricity. The Fine Filters unit was unique in that the teacher targeted instruction to address the *why* more so than the other units. Although most her students stated the reasons why the new nanomembrane filters worked, they still demonstrated areas of misunderstanding about relative size and scale of objects to be filtered out of water compared with the pore size of the filtering membrane.

Prior research suggests two possible frameworks to consider when thinking about students' learning *what* better than *why* regarding nanoscale science and technology. One, as described by

Schwartz and Sadler (2007) and Fischer & Granott (1995), uses the principle of micro development as a framework for looking at curriculum and student learning in science. This principle explains that short-term learning goes through the same stages as long-term developmental growth: a series of sensorimotor experiences, followed by student representational tasks, ending with the ability to abstract a general concept. The implication is that without this sequence, a student will encounter difficulties trying to learn abstract concepts. While NanoSense units were designed to include many hands-on activities (labs) and representational tasks (creating or analyzing process animations), these materials were often not used by teachers due to time constraints. Thus many of the implementations were heavy on teacher-presentation. We suspect that the low use of the student-centered activities may have been detrimental to students' efforts to master the challenging concepts in the units.

Another framework that might explain why student learning often remained at a superficial level is described by Donovan & Bransford (2005), who explain that new student learning must connect with prior experiences for the new ideas to make sense to students. Our NanoSense curriculum unit was challenged to offer a curriculum that produced meaningful science learning about nanoscale science and technology in classrooms whose students were often under prepared in foundational conceptions related to the model of the atom. This issue is discussed further in the section on Problems with Foundational Understandings.

Students have difficulties relating the distinctness of the nanoscale with the continuity of scientific principles

One of the reasons that nanoscale science has been of particular interest to educators is because it offers the opportunity to show students the continuity of science across multiple disciplines and size scales (Sabelli et al., 2005; Schank, Krajcik & Yunker, 2007; Krajcik et al., 2007). At the same time, the nanoscale is seen as an interesting and exciting area for investigation in part because "stuff acts differently" at this level. This apparent tension is can be explained through the logic of complex systems where small quantitative changes in a continuous property of a system can lead to discrete qualitative changes in the state of the system; this idea has been highlighted as an important scientific concept for students in the 21st Century (Sabelli, 2006). Based on the results of our study, we suggest that the relationship between continuous and discrete changes may be a "big idea" for nanoscience education as well.

Difficulties in understanding the relationship between continuity and discreteness were seen primarily in the Size Matters Unit. For example, in relation to a question on the relative dominance of the forces, instead of conceiving of forces along a continuum of influence, many students saw gravity as something that simply did not apply at the nanoscale. In contrast, when describing how we "see" at the nanoscale, students showed a tendency to think in a continuous way about how microscopes could be made stronger, instead of focusing on how or why they needed to be made differently for the nanoscale. The tension between the idea that the same laws of science apply at the nanoscale and the notion that "things are different at the nanoscale" seems to be problematic for students since it is not clear to them when things are the "same," when they are "different," and why. Related to this, students readily accepted the idea that properties of substances could simply be different at the nanoscale without explaining why or how this was so. Again, these discrete qualitative changes in properties are caused by underlying continuous changes in the fundamental interactions of matter that leads to these properties, i.e. through variations in how the matter interacts with light or affects the conduction of electrical current. A related issue was seen in the Clear Sunscreen Unit, where students had difficulties in thinking about wavelength as varying along a continuum when the labels used to refer to different sections of the wavelength (e.g. UVA, UVB) reify them as if they were two separate entities.

Problems with Foundational Understandings

Students also had difficulties across units with a number of foundational understandings. For example, most units included a focus on different sizes of matter. Throughout all units students had difficulty relating and distinguishing between single atoms or ions dissolved in a solution and larger aggregations of atoms or ions of the same substance. For example, in Fine Filters, students didn't understand how or what it meant for iron (something they commonly encounter in bulk form) to be dissolved in water. During traditional chemistry classes, there is a relatively small section within the topic of solutions that explains these ideas. This topic is sequenced after the model of the atom and all types of bonding have been taught. We had no evidence, however, that students comfortably applied the notion of larger size aggregates of individual atoms, ions, and molecules to their understanding of particle size within the nano units. In addition, Teacher M revealed that though her students had studied concepts of the model of the atom, ionic and molecular bonding (specifically taught to promote better understanding of Clean Energy and Fine Filters), that they still had some difficulty with applying these concepts to new situations. Student questions on “confusion” cards (e.g., "What is it that an electron keeps doing?", "What is a dipole? Which atom is positive? Negative?", "What does valence mean?") highlighted that some students lack adequate background knowledge to be able to deeply understand the interaction of water, ions, molecules, and small aggregates of substances.

In terms of how light interacts with matter, in the Clean Energy unit students seemed to think that light somehow magically “released” electricity from the cells and did not understand the underlying principles by which energy transferred to electrons allows them to overcome their attraction to the nucleus. In a related problem, students did not always seem to realize that the flow of electrons and “current” were the same thing, nor did they fully understand why a complete circuit is needed in order to have a current. Difficulties with the interaction between light and matter were also seen in the Clear Sunscreen unit, in which students had difficulties in differentiating between the absorption and scattering processes.

One of the reasons students may have had difficulties with the deeper science content emerges from a difference in the anticipated and actual conditions of the units’ use. The units were designed to be used in a standard college prep chemistry class, but teacher interest in using the units arose primarily for classes earlier on in the standard high school sequence. Only three of the six classes in the evaluation had taken or were currently taking chemistry (the chemistry classes in which the SM and CE units were used and the biotechnology classes in which the CS unit was used); the students in the other classes (environmental science and biology) didn’t have the chemistry background we expected. The academic background of the students is critical to understanding why many of the students didn’t get some of the more intricate science content.

How did students fare when they previously had received instruction in the prerequisite background topics? Our study showed mixed results. In one instance, Teacher M specifically prepared her students for the Fine Filters unit by spending class time on atomic structure and bonding just prior to the teaching of the unit. According to Teacher M, her students started the Fine Filters unit with a "better understanding" when compared to the previous year's students, when she implemented the unit without such preparation. She felt that the more background knowledge her students had, the more they could "own" the new information from the NanoSense unit. She noticed that when she placed greater emphasis on teaching the details of atomic structure compared to the prior year, her students felt that they had more background and that the material in the Fine Filters unit was "less overwhelming." Her students actively discussed the Fine Filters labs, had "animated" discussions in class, and overall had engaging questions and statements about the material. According to Teacher M, her students really felt like they were using the science they had learned and that they liked the feeling of being scientists.

In contrast, for the Clear Sunscreen unit, introduction to prerequisite topics in a prior class didn't necessarily provide the needed grounding in the concepts. We had expected that the $11^{th}/12^{th}$ grade biotechnology students would have fewer difficulties with the distinctions between molecules and ionic compounds than the 9^{th} grade biology students since they had taken chemistry previously. However, we found that both the biotech and biology students exhibited the same kinds of confusions.

One takeaway from our research may be that the NanoSense units should be taught soon after important prerequisite topics are taught. The units provide information on alignment to prerequisite topics as well as alignment to national standards. The prerequisite and alignment information help a teacher find the best place(s) in his or her own curriculum to teach the NanoSense units and determine which prerequisite topics to focus on in advance. Although we did provide prerequisite information for all of the NanoSense units, it was not clear from our research to what extent this information was used. What does a teacher do with a checklist of prerequisites? In Teacher M's case, our sense was that her experience of implementing the Fine Filters unit in the prior class year was the primary driver in what prerequisite topics she introduced her students the following year.

Determining where in the school year to teach the NanoSense units highlights a fundamental question that we've considered from the beginning—are the NanoSense units a vehicle for teaching nanoscience, or are they a tool for reinforcing basic science concepts? Since our units are designed to be inserted within existing curriculum, we had the constraint of making them small enough to be easily implemented, but detailed enough to expose important supporting science. Thus, the units focus on teaching nanoscience concepts and getting students excited about nanoscience, but rely on the teacher to place them strategically in the curriculum so students have adequate and relatively recent exposure to prerequisite science concepts.

Evaluation Question 2: Student Attitudes Towards Science

Does learning the NanoSense Curricula change students' attitudes towards science in general?

a. Does use of the NanoSense Curricula make students see science as more relevant to their lives?
b. Does it make them more interested in a career in science?

Overall, the results related to the effect of the NanoSense Curricula on students' attitudes towards science were mixed. We did find evidence in three out of the four classes surveyed that students' overall attitudes changed as a result of using NanoSense curricula, however gains on the attitude survey were primarily due to a change in perception of the usefulness of science in everyday life. No change was seen in the other questions on using science to help make choices, explaining things to others, or understanding worldwide problems. Our results did not provide support for an effect on students' interest in a career in science. It is noteworthy, however, that significant attitude gains were found for a 1-day implementation (Clear Sunscreen in the biotech class). This suggests that even a brief exposure to nanoscience can have an effect on student attitudes towards science. Students' positive attitude and interest in the units was also supported by classroom observations, and student comments on the "aha/wow" cards. Abundant examples from student "aha/wow" cards suggest that students were interested in and felt they learned about societal issues. Students seemed very motivated by the issues related to the world energy and water problems, use and functioning of sunscreens, and how filters work. This aligns with prior research (e.g., Freedman, 1997; Lee & Erdogan, 2007) suggesting that instruction that incorporates real-world issues and hands-on activities can improve student attitudes about science.

In their reflections, the teachers seemed to feel that one of the main benefits of using NanoSense activities was that the activities got students excited about learning science. In several cases teachers felt that the combination of this excitement with students understanding the big picture ideas behind the science, if not all of the fine-grained details, would have long-term payoffs for learning. However, while some effect on student attitudes was found, it was primarily related to the "usefulness" of science and not to career aspirations. This raises several questions. For example, if the primary impact of using NanoSense curricula is that it gets students excited about learning science, is that enough of a benefit to justify use of the materials? Is seeing science as more useful a first step toward larger change? Could longer-term interventions—perhaps including more focus on what nanoscientists actually do—have an impact on career aspirations? Answers may depend upon the context of the implementation, but encouragingly, improving student attitudes about science has been found to have a significant impact on student performance the likelihood of students pursuing science as a career (Tai, 2006; Schommer, 1994).

Evaluation Question 3: Viability of Key Features of the NanoSense Approach

> What features of the NanoSense approach are key supporters of or detractors from its viability as a model for teaching nanoscience to high-school students with respect to the following areas?
>
> a. Selection of content
> b. Fit with traditional science curricula
> c. Delivery structures for the materials
> d. Teacher professional development

Review of Key Features of the NanoSense Approach

The NanoSense approach to teaching nanoscience to high-school students created a set of four units centered on interesting applications of nanoscience. The units were mapped to existing science standards and a "roadmap" was created to help teachers search for activities related to topics in the standard high school curriculum for each four common types of science classes (chemistry, biology, physics, environmental science). Professional development was integrated into the approach from the beginning, starting with a process of co-design with teachers and following through with a series of workshops and ongoing individualized support available from the research team. Below we discuss the major themes that emerged from our findings related to the four areas outlined above.

Selection of Content

In addition to organizing units around learning goals to ensure that students learn what is intended (Krajcik, McNeil & Reiser, 2006), research clearly shows that it is also important to consider students' motivation when developing materials for learning (Blumenfeld et al., 2006) if we want students to engage with the materials. We focused three of our four units on how applications of nanoscience relate to students' everyday lives with the goal of contextualizing the scientific concepts, making them meaningful to students, and thereby giving them motivation for learning the new ideas (Krajcik & Blumenfeld, 2006). We explicitly chose to focus on real-world topics that affected students personally (e.g., their health) or were some of the biggest problems facing the world (e.g., energy and water) for which nanoscience could enable important, innovative breakthroughs[1].

Our observations, teacher reflections and student "wow" cards suggest that students were indeed engaged by the three units that focused on specific applications of nanoscience—Clear Sunscreen, Clean Energy, and Fine Filters—and that the selected topics mattered to students. In addition, significant gains were found in three out of the four implementations in which the attitudes towards science survey was administered. Despite these positive findings, we encountered a tension between "hooking" students and getting the science content across. For example, in the Clean Energy unit, students were really engaged with and excited about the content, but showed many inaccurate or surface-level understandings related how nanoparticles convert solar energy into electrical energy. Teacher M specifically noted that she thought the students were excited and engaged despite the fact that they might not have understood all the details and the science in the unit. A similar phenomenon was observed for the Clear Sunscreen unit, where a large number of students wrote "wow" statements related to the protection that sunscreen provides, but only a small portion of these focused on the mechanism of how sunscreens protect us as opposed to more superficial issues related to different levels/kinds of protection. This is similar to the trend we saw in the analysis of student test answers where students focused most on the unit issues as they related to their role as consumers rather than on the deep science content.

[1] Note that while the Size Matters unit did include a lesson on applications of nanoscience, the lesson provided only a brief survey of applications and was not used in the Size Matters implementation conducted for this evaluation.

There are many potential factors contributing to the high engagement / low focus on science content results found. Based on the results of this evaluation, we suggest that one may be that when studying "real world" applications, students tend to focus more on their relevance to their lives and less on the underlying science. Harp & Mayer (1998) offer a potential explanation for such an effect in their finding that "seductive details" in text passages can lead students to organize their understanding of the material around these salient features rather than around the main ideas of the text. If a similar effect is occurring here, it would present an inherent tension with the use of relevant applications to motivate student interest and suggest that such use may need to be more carefully structured. Of course this is a hypothesis that needs to be tested; given an affirmative finding, we might then start to explore pedagogical techniques to counteract this tendency.

Regardless, student engagement in the NanoSense units is noteworthy in light of research that shows that interest in science and career expectations are better predictors than achievement level of which students will go on to earn degrees in physical science (Tai, 2006). The limited numbers of U.S. students who choose technical careers has led to a concern about whether the United States will have a workforce that is educated enough to take full advantage of future career opportunities, particularly in nanoscience. Encouragement of interest and exposure to motivating real-world applications should not be ignored by an exclusive focus on raising test scores if the larger goal is to impact students' future career plans.

Fit with Traditional Science Curricula

While our lessons were originally designed to integrate nanoscale science into chemistry classes, the teachers who were interested in using our materials and who came to our professional development workshops were from a variety of disciplines. This discovery prompted us to undertake a curricula mapping effort in which we aligned our units with traditional science curricula in chemistry, biology, physics and environmental science in order to try to identify entry points where teachers could connect the units to their regular classroom topics. In one sense, the effort was very successful: many connections and entry points were identified. However, the endeavour also uncovered several challenges for the integration of nanoscience into traditional science curricula.

First, in general, in the connections identified, the nanoscience topics were found to *build on* (as opposed to incorporate) the foundational topics addressed in the traditional science curricula. In other words, while the nanoscience content could serve as motivation for, or an application of, the traditional science concept, the depth of use of the concept within the nanoscience content was at such a level that it was be difficult to teach the concept concurrently with the nanoscience. This challenge results in part from our decision to center the units on interesting applications. Even the more straightforward applications integrated multiple scientific ideas, requiring a high level of fluency with the underlying foundational concepts. This may make an application-centered approach difficult to integrate via a "replacement" model.

Second, while we were able to map the content of our units to existing standards and curricula, teachers still found it difficult to conceptualize how to integrate the topics into their lesson and how to help students integrate nanoscale science ideas into their existing science understandings.

This seemed to be a problem of vision in which teachers had problems “seeing” how to combine nanoscience with their existing lessons because they weren’t used to looking at nanoscale materials within the context of existing curricula. With the extensive professional development we provided our partner teachers over the course of the four years of the project, they began to be able to think about these issues. Teachers who had the opportunity to implement our units more than once showed a large jump in the sophistication with which they conceptualized how to integrate the NanoSense materials the second time around. The take-away is that getting teachers to figure out how to integrate nanoscience into their curricula is not just a matter of providing the curriculum maps; it requires sustained professional development to support the process of envisioning the multiple connections to ideas within their traditional science framework.

Delivery Structures for the Materials

One of the main concerns that teachers expressed was a lack of time in their school year to cover the entire curriculum required by state content standards and assessed annually. Teachers struggled to find a window of opportunity to 'fit in' new curriculum, when they could barely manage to teach the mandated curriculum by the time their students were tested on it. Yet, our partner teachers claimed that nanoscale science and technology was a relevant, interesting, and accessible topic to students, and they were willing to make the extra effort to find a way to fit in to their curriculum. Even with such efforts, we found that teachers simply had very little flexibility in their traditional science classes. For example, while Teacher M was comfortable with the materials and able to do two implementations (lasting five and four days respectively) with her environmental science class, in her regular chemistry classes she reported that she had more success using the units as “bits and pieces.” She also pointed out that while the alignment of the environmental science curriculum with the NanoSense units is straightforward, for chemistry, the topics covered (e.g. water chemistry, energy) are found scattered throughout the standards.

A particular issue related to implementations and time-constraints is that when teachers did use the curriculum, there was often less use of the hands-on activities than we expected based upon teachers strong support of such activities during the development process. For example, Teacher C didn’t use any hands-on activities for the Size Matters unit, and in the Clear Sunscreen implementations, most of the PowerPoint slides were used but only a few of the hands-on activities were used. Although hands-on activities take time, they may be critical for understanding. For example, Stohr-Hunt (1996) found that students who engaged in hands-on activities frequently (e.g., one or more times a week) score significantly higher on a tests of science achievement than students who engaged in hands-on activities less frequently (e.g., once a month or less). Not surprisingly, time was a core issue in teacher adoption of the curriculum, and specifically in use of hands-on activities, which often take more time than a presentation covering the same content.

In discussions with our partner teachers after having gone through the experience of helping to design and use the units, they concluded that nanoscale science is best integrated thoroughly within the regular curriculum. They claimed that now that they better understood nanoscale science, they were in a better position to fit those key concepts into their standard curriculum in a seamless way throughout the school year. With the exception of the non-traditional (environmental science) class, teachers felt that this was a more realistic approach to incorporate nanoscience into their classrooms than trying to find space for full units. Indeed, after the implementations described here, teachers G and M applied for and received grant money to create kits with basic equipment and materials for each NanoSense unit and train other science teachers in their school to make it as easy as possible for them to integrate NanoSense activities into their science classrooms. Thus we conclude that while the full units may work in certain flexible settings (e.g. non-traditional or integrated science classes, after-school workshops), for traditional science classes, a more realistic model for integration may require knowledgeable teachers to integrate smaller pieces of the units "on the fly" when they align (e.g., as indicated by the alignment charts) with planned topics in their curriculum.

Teacher Professional Development

Teaching nanoscience poses challenges to most secondary science teachers who have majored in one discipline. Even though we developed extensive teacher support materials, engaged teachers in their development of the curriculum, provided alignment charts of where the curriculum addresses core science topics, and witnessed great enthusiasm among our teachers, many were still hesitant to use the curriculum. The novelty of the content, combined with the newness of the field, raised pedagogical and content demands that many teachers were not prepared to deal with. When asked about barriers to implementation, teachers indicated that their comfort level with the material was a bigger challenge than resources.

Generally, as teacher comfort with NanoSense materials grew, so did their willingness to integrate the materials into the classroom and their success in doing so. For example, teacher M was far more successful at helping students to learn the second time she taught Fine Filters and Clean Energy. The first time teaching these units, she did not have a full understanding of the science in the units nor a clear vision of potential areas of learning difficulty for her students. The second time, she prepared her students to be in a better position to learn the nanoscale science modules by enriching their science background before the units began. She was also better prepared by knowing what to emphasize in her teaching, giving directions and information more clearly, and bringing in motivating real-life examples related to the curriculum.

In some of our classroom observations, we saw that lack of familiarity with the content made it difficult for teachers to stimulate discussion by asking follow-up questions and to identify and address student misconceptions. Teachers are not able to know all the answers to students' (and their own) questions, and many questions go beyond our current understanding as a scientific community. To help teachers engage these challenges, we recast them as opportunities to model the scientific process and provide concrete strategies for how to do so. We also provided ongoing professional development experiences—such as weekend workshops and curriculum design meetings—to improve our materials and provide learning opportunities for teachers. Still, we found that the difficulties associated with preparation of teachers to teach an interdisciplinary field such as nanoscience are great. In the end, only teachers who had collaborated in the development of the units integrated them into their classrooms. Some of the activities they participated in that may have helped them feel better prepared to use the curriculum were reviewing the materials during their creation, developing additional materials to help scaffold students' learning, teaching other teachers in a workshop setting, and asking "just-in-time" questions to the development team when they had questions about the content. Despite this extensive preparation, two of the four teachers still welcomed the opportunity to have their implementation co-taught by a development team member.

LIMITATIONS OF THE EVALUATION

Sample

The sample in this evaluation was limited in two ways. First, the overall number of implementations and students was relatively small. While all of the units were used in real classrooms, most were taught by only one teacher meaning that any particular strengths or weakness of the individual teachers could strongly influence the results. In addition, only two of the implementations were in standard-level high school classes; three of the implementations were in low-performing / ESL classes and one was an advanced elective. In addition all but one of the implementations were conducted at high achieving schools. As discussed earlier, the small, non-representative sample was dictated the fact that only our partner teachers were willing to implement the units in their classrooms. Thus while our findings can be informative about the possibilities and challenges of introducing nanoscience into high school science classrooms, caution must be used in generalizing to the larger high school science student population.

Fidelity of Implementation

Fidelity of implementation was a great challenge in this evaluation. In order to study how the materials would actually be used in classrooms, we allowed the implementing teachers to choose what parts of the materials to use and how. In order to get as much participation as possible, we had a very loose minimum requirement for implementation (use of the primary slide set for the unit). This resulted in a wide range between implementations in terms of time and the amount of materials used. No teacher implemented an entire unit, and as discussed earlier, many teachers chose not to use the hands-on lab activities.

Because of their familiarity with the unit materials and goal, the implementations that were co-taught by a NanoSense team member, had a higher level of fidelity of implementation than those that were taught by a teacher alone. However, this also limits the external validity of these results, since our co-teaching developers had higher levels of expertise in nanoscience than the average classroom teacher.

Instrumentation

Each unit's pre/post tests were targeted to match its learning goals, and all instruments were reviewed and refined by the research team. However, the instruments were not pilot tested to further refine the learning measures. Meaningful pilot testing of the instruments would have required participation of students who were familiar with the nanoscience content and given the challenges we encountered in getting the units used, we did not have sufficient participants to do this. Some issues with specific test questions were revealed in evaluating the student post-test answers. For example, some students misinterpreted what some questions were asking for, or gave overly simplistic answers that did not go into the depth we desired. In such cases, it is difficult to assess whether students didn't understand the concepts, couldn't articulate them, or simply did not choose to explain them. Some questions were worded using overly general language, which may explain this phenomenon. In future studies, the question language needs to be more detailed and prompting to elicit discussion of specific target concepts.

Data Collection

Not all data sources were collected for all classrooms.

CONCLUSION

Despite the considerable challenges, the results of this evaluation indicate that it is fundamentally possible to introduce nanoscale science at the high school level to engage and motivate students and increase their understanding of nano-related science concepts. In particular, the use of new and exciting applications may have great purchase with students, but many nano-related concepts are difficult for students and often build on basic scientific ideas with which they are not yet fluent. Teaching or reviewing these basic scientific ideas immediately prior to teaching the related nanoscience topic may be an important strategy for success. In addition, given the tendency for students to focus on the “consumer payoff” aspect of nanoscience, it’s important to explicitly push students to focus not only on the phenomena and applications related to nanoscience but the mechanisms underlying why these are possible. Related to this, greater emphasis on the hand-on activities, as opposed to just the slide sets may be warranted. Finally, explicit treatment of the distinctness of the nanoscale in the context of the continuity of scientific principles may be important to help students conceptualize how nanoscience relates to other science they have learned.

In terms of models for integrating nanoscience into high school classrooms, this evaluation suggests that an approach in which teachers weave nanoscience content into their standard curriculum (versus conducting dedicated full units) may be a fruitful strategy to pursue—particularly if one employs a tactic of teaching nanoscience topics in conjunction with the related basic science concepts, as discussed above. However, this approach may make teacher comfort level even more important for implementation to occur. Given the challenges we observed in this area, effective teacher professional development may be the next key challenge for nanoscience education. Beyond materials, workshops, and opportunities to practice-teach, what teachers found most useful was having a knowledgeable nanoscience expert available to support the process in real time, as needed. Creating “nanoscience liaisons” who are available to provide support to implementing teachers might be one approach to help teachers “get up to speed” and feel comfortable with nanoscience concepts.

Still, we expect that teaching nanoscience will pose challenges to most secondary science teachers who have majored in one discipline. Since most teachers become certified in a single scientific discipline, science methods courses for preservice teachers may need to begin to address interdisciplinary connections to prepare teachers to work with innovative, and emerging science topics such as nanotechnology. Looking forward, nanoscale science challenges the learning and science research community to explore new pedagogies to support the goal of helping students experience science in an interdisciplinary fashion.

REFERENCES

Bodner, G (2007). Strengthening conceptual connections in introductory chemistry courses. *Chemistry Education Research and Practice, 8*(1), 93-100.

Blumenfeld, P. C., Kempler, T. M., & Krajcik, J. S. (2006). Motivation and cognitive engagement in learning environments. In R. K. Sawyer, (Ed.), *The Cambridge handbook of the learning sciences* (pp. 475 - 488). New York: Cambridge University Press.

Chittleborough, G. & Treagust, D. (2007). The modeling ability of non-major chemistry students and their understanding of the sub-microscopic level. *Chemical Education Research Practices, 8* (3), 274-292.

Donovan, S. & Bransford J. Eds. (2007). *How students learn.* Washington, DC: National Research Council.

Fischer, K.W., & Granott, N. (1995). Beyond one-dimensional change: Parallel, concurrent, socially distributed process in learning and development. *Human Development*, 38, 302-314.

Freedman, M.P. (1997). Relationship among laboratory instruction, attitude toward science, and achievement in science knowledge. Journal of Research in Science Teaching, 34, 343 – 357.

Harp, S. F. & Mayer, R. E. (1998) How seductive details do their damage: A theory of cognitive interest in science learning, *Journal of Educational Psychology, 90*(3) 414-434.

Hurd, P. D. (1991). Why we must transform science education. *Educational Leadership 49*(2): 33 - 35.

Krajcik, J. S. & Blumenfeld, P. (2006). Project-based learning. In R. K. Sawyer (Ed.), *The Cambridge handbook of the learning sciences*. New York: Cambridge University Press.

Krajcik, J., McNeill, K., & Reiser, B (2006, April). A learning goals driven design model for developing science curriculum. Paper presented at the Annual Meeting of the American Educational Research Association, San Francisco, CA. Retrieved October 29, 2008, from http://hi-ce.org/papers/2006/Krajcik_McNeil_Reiser_Assessment_AERA_final.pdf

Krajcik, J., Stevens, S., Schank, P., & Stanford, T. (2007). Big ideas in nanoscience. Presented at the Workshop on Nanoscale Science and Engineering Education sponsored by the National Science Foundation. January 11-12, Washington, DC. Available at http://www.nanoed.org/news/docs/011207/JoeKrajcik-NSF_Nano_Big_IDEA.pdf

Lee, M., & Erdogan, I. (2007). The effect of science-technology-society teaching on students' attitudes toward science and certain aspects of creativity. *International Journal of Science Education, 29(*11), 1315-1327. Routledge.

Onwu, G. & Randall, E. (2007). Some aspects of students' understanding of a representational model of the particulate nature of matter in chemistry in three different countries. *Chemical Education Research Practices, 7*(4), 226-239.

Sabelli, N. (2006). Complexity, technology, science, and education. *Journal of the Learning Sciences, 15*(1), 5-9.

Sabelli, N., Schank, P., Rosenquist, A., Stanford, T., Patton, C., Cormia, R., & Hurst, K. (2005). Report of the workshop on science and technology education at the nanoscale, DRAFT Technical Report, Menlo Park, CA: SRI International.

Sandoval, W., A., & Morrison, K. (2003). High school students' ideas about theories and theory change after a biological inquiry unit. *Journal of Research in Science Teaching, 40*(4), 369-392.

Schank, P., Krajcik, J., & Yunker, M. (2007). Can nanoscience be a catalyst for educational reform? In F. Allhoff, P. Lin, J. Moor, J. Weckert (Eds.), Nanoethics: The ethical and social implications of nanotechnology. Wiley Publishing.

Schommer, M. (1994). Synthesizing epistemological belief research: Tentative understandings and provocative confusions. *Educational Psychology Review*, 6, 293 – 319.

Schwartz, M & Sadler, P., (June 2007). Empowerment in science curriculum development: A micro developmental approach. *International Journal of Science Education*, *29*(8), pp. 987-1017.

Siegel, M., & Ranney, M. (2003). Developing the Changes in Attitude about the Relevance of Science (CARS) questionnaire and assessing two high school science classes. *Journal of Research in Science Teaching, 40*(8), 757-775.

Stohr-Hunt, P. (1996). An analysis of frequency of hands-on experience and science achievement. *Journal of Research in Science Teaching, 33*(1), 101-109. Wiley Publishing.

Tai, R. (2006). Planning early for careers in science. *Science, 312*(5777), 1143-1144. Washington, DC: AAAS.

Tinker, R. (2006). *Nanoscience and the new secondary science curriculum*. Presented at the 2006 Workshop to Identify and Clarify Nanoscience Learning Goals. Boston, MA: The Concord Consortium.

Yilmaz, A. & Alp, E. (2006). Students' understanding of matter: the effect of reasoning ability and grade level. *Chemical Education Research and Practice, 7*(1), 22-31.

APPENDICIES

Appendix A: Questions or statements of confusion submitted by students in the biology class on the Clear Sunscreen Unit

(Ideas mentioned by 5 or more students are highlighted in bold)

Electromagnetic Radiation

- Which part of the sun rays give Vitamin D?
- What is a photon?
- Where are the different kinds of radiation found?
- How do you measure wavelength?
- How are visible and infrared visible to the human eye?

UV Light

- **What's the difference between UVA and UVB?** (10 students)
- **What does broad spectrum mean?** (5 students)
- What will happen if UVC gets to Earth? (2 students)
- How can both UVB and UVA be present in a sunscreen?
- Is it more important to protect from UVA or UVB rays?
- How effective is broadband protection?
- What does UV light do?
- If we keep damaging the ozone, how long is it going to take the UVC to come to earth?
- How can we protect the ozone?
- Are we in any danger of being hit by UVC rays?
- Does global warming affect the amount of UV rays going into the atmosphere?

Skin Color & Sun Radiation

- If darker colors attract more light, then why are people who are descended from people who used to live near the equator dark skinned? Wouldn't that mean more radiation from the sun?
- Do people w/ lighter skin color get sun burned more easily?
- Does genetics play any factor in skin cancer or skin reacting to the sun?

Sunscreens (Protection)

- What does SPF stand for and mean? (2 students)
- What is the measure of "SPF" and what is the range of SPF # a sunscreen can have?
- What are the requirements to be a "factor" in SPF?
- Why use SPF 15 when you can use something higher? What's the difference?
- Does the amount of sunscreen applied affect the level of protection and SPF?
- How does the opacity of the sunscreen affect the SPF?
- How do the chemicals block UV light?
- How do you increase the strength of sunscreen?
- Is it possible to make a sunblock with less opacity but high UV blockage ability?
- Why do most of the ingredients that are organic not protect against UVA?
- Do all products/ingredients that protect from UVA rays have a white color?
- Are sunscreens more effective w/ more or less active ingredients?
- What do the active ingredients in a sunscreen do?

- Does a t-shirt provide better or worse protection than sunscreen?
- If a bottle of sunscreen of a well known brand claims that is it good for protection against UVB and UVA should I believe it?

Sunscreens (Appearance)

- Why do the inorganic ingredients clump the way they do?
- Are creams/lotions for sunscreen that is able to be smeared and absorbed well on skin not made of inorganic [ingredients]?
- Are organic sunscreens never translucent (always have a high opacity)?
- Do inorganic ingredients in a sunscreen make it harder to spread across your body? Is it thicker?
- Can opaque sunscreen come in spray form?
- How do a sunscreen stick and lotion differ? (accuracy, trustworthy, how long it lasts, price quality)

Sunscreens (Ingredients)

- What are "nano" ingredients? (4 students)
- How can you tell if a sunscreen has nanoingredients? (2 students)
- Why do we use or need nanoingredients?
- How many ingredients are the limit?
- If only certain ingredients are active, why does the sunscreen need all the other ones?
- Why do all the active ingredients start with an O?
- What does Homosalate do?
- Zinc oxide is also a vitamin supplement – why is it in sunscreens?
- Why is oxygen part of both organic and inorganic ingredients?
- Is oxygen a necessary ingredient in sunscreens?
- What does "inorganic" mean in this scenario?
- Is organic or inorganic sunscreen better?
- What's the difference between sunscreen for sensitive people and surfers?

Other

- What is so important about nanotechnology?
- Exactly how small does "nano" mean?
- Why do we use nanotechnology?
- Why does the UV [bead] change back from purple to clear?

Appendix B: Aha or wow statements submitted by students in the biology class on the Clear Sunscreen Unit

(Ideas mentioned by 5 or more students are highlighted in bold)

Electromagnetic Radiation

- The shortest wavelength equals strongest energy (2 students)
- Sun rays = electromagnetic wave. [The sun] emits EM radiation (IR, vis, UV
- UV, visible, infrared [have] different wavelength, frequency and energy level
- I never thought of light energy having impact on your skin
- The sun does not emit Xrays, gamma rays, microwaves or radio waves

UV Light

- **Wow! I didn't know what UVC is!** (5 students)
- UVC gets blocked from ozone, does not reach us (4 students)
- UVA - penetrate into skin deeper (long term damage) (4 students)
- UVB - higher energy than UVA & sunburn is immediate reaction (3 students)
- It's interesting that UVA penetrates the deepest in your skin even w/ the lowest energy of the UV (2 students)
- I didn't know that UVB also causes skin cancer (2 students)
- I didn't know there was 3 different types of UV (UVA, UVB, UVC).
- UVC is strongest, but doesn't reach us b/c the ozone layer protects us
- If the ozone layer keeps shrinking, UVC will get through.

Dangers of UV Exposure

- Why use sunscreens? Too much unprotected sun exposure can lead to premature skin again, sunburns and cancer
- The amount of people getting skin cancer is increasing, but the ability to catch the disease soon is increasing [too].
- 50% of all cancer cases are skin
- In 2050 1 out of 10 person is going to have skin cancer
- Skin cancer rates are rising (~50% of cancer cases, 1 person dies every hour, > 1 million cases each year)

Sunscreens (Protection)

- Sunscreen protects against multiple rays
- Different ingredients can protect at different levels.
- I didn't know that inorganic ingredients protect better than organic products
- There are multiple levels of strengths in sunscreens.
- Inorganic product zinc oxide goes on white, protects the most, now there is gel sunscreen
- It was interesting to learn how sunscreen blocks sunlight – through reflecting & absorbing
- Sunscreen absorbs and reflects the sun rays to protect us
- Light blocking – absorption, reflection
- I was surprised to see that the transparent sunscreen provided about the same amount of protection as the opaque sunscreens

- Light is “blocked” either absorbed or reflected (can also be transmitted)
- [picture of rays coming to skin and either being reflected, absorbed or transmitted]
- Each molecule in organic ingredients absorbs a different energy (absorbs high energy -> release low energy (infrared)
- The UV blocking ability depends on opacity
- High SPF – stronger protection
- SPF = sunburn protection factor
- Higher SPF – more protection from UVB

Sunscreens (Ingredients)

- I was surprised that some ingredients in sunscreens are not good (2 students)
- First item on the sunscreen ingredients list is greatest, last item is smallest
- Too much of an ingredients in sunscreen can cause harm to the body
- Some of the sunscreen have completely different ingredients.
- Oxybenzone is in both sunscreens [I looked at]. It must be an essential ingredient.
- There are living ingredients in sunscreens.
- Many sunscreens have a lot of the same active ingredients
- Sunscreens require different active ingredients for different purposes (baby, oil-free, etc.)
- There is twice the amount of homosalate and there is any other ingredient [in the sunscreen we looked at]
- Both sunscreens [we looked at] are oil-free/non-greasy and waterproof and sweatproof.
- Trader Joe’s sunscreen retains SPF after 80 min in water, contains z-cote.
- All-Terrain sunscreen contains antioxidants, doesn’t clog pores, z-cote.
- There is sunscreen designed for skiers and surfers.
- The Coppertone sunscreen has UVB and UVA.

Sunscreens (Other)

- I think it it’s interesting that inactive ingredients in sunscreen are used to influence the appearance, scent, texture, and chemical stability of the sunscreen (2 students)
- I never thought of all the factors of putting on sunscreen
- Sunscreens were only invented in the 1940s
- Sunscreen first developed for WWI soldiers

Other

- Nanotech is very interesting and its cool that it is a new developing technology
- We need to test many more solutions to fully confirm our observations (such as white t-shirts, sunglasses, makeup etc.)
- It’s really cool how the bead changes color like that
- I didn’t know there was such a thing as a microspoon.

Appendix C: Questions or statements of confusion submitted by students in the environmental science class on the Clean Energy Unit

(Ideas mentioned by 5 or more students are highlighted in bold)

Use of energy and fossil fuels

- What is the energy problem?
- How does energy lead to other problems?
- Why is population the last one on the top 10 list?
- How is oil used? (2 students)
- 714 lbs of coal a year for 1 light bulb? (2 students)
- Why is growing carbon significant?
- The chart of barrels of oil that are demanded is unclear.
- What is the difference between gas and diesel?
- What is the amount of oil left in the future?

Science

- What is a buckyball? (4 students)
- More energy states in a molecule than in individual atoms?
- What is electron transition?
- Light with high enough energy excites electrons in dye molecules?
- Chlorophyll can only absorb blue and green?
- What are terawatts?
- What is tar?

Technology

- Why don't we have technology to solve the problem?
- How to make nano particles into solar panels so that it is inexpensive and small and flexible?
- Dye-sensitized cells are the flexible solar panels?
- How reliable is solar energy?
- How do you restore the electricity?
- Photovoltaic (solar) panel?
- How is oil used to make plastic?

Appendix D: Aha or wow statements submitted by students in the environmental science class on the Clean Energy Unit

(Ideas mentioned by 5 or more students are highlighted in bold)

World problems

- **Energy is the top problem facing the world** (14 students)
- **The top ten problems facing the world** (5 students)
- Population is last on the list
- The water crisis
- You solve one problem (energy), you can solve others (like water crisis) (3 students)
- The world is heavily dependent on oil, gas
- Disintegration of acid rain, side effects of coal burning
- Life is going to be extremely difficult for later generations

Use of energy and fossil fuels

- **The rate of use of barrels of oil /1000 barrels per second is being used** (27 students)
- **Burning a light bulb for 1 year = 714 lbs coal** (8 students)
- **The U.S. consumes 25% of the world's energy but has 5% of its population** (5 students)
- How much gas we use for heating, cooking, etc. (2 students)
- Non-fossil fuel = solar, wind, water, nuclear, burning bio/wood
- Oil is distilled or separated into many carbon-based products (3 students)
- How oil is used
- The products are used to power devices like cars, home heaters (2 students)
- Ethanol is made of corn
- Plastic comes from crude oil (2 students)
- 1 terawatt will run 13 million U.S. homes a day (2 students)
- 14 terawatts needed

Nanoscale science

- One billionth (10^{-9}) is small! (4 students)
- Buckyball
- Particles don't behave the same way
- Molecules absorb wider range of light compared to atom
- Atoms – light energy is either absorbed or reflected back

General science

- 1 terawatt is 10^{12} (3 students)
- Absorption occurs only when the energy of the light equals the energy of transition of an electron (2 students)
- Ionic compounds don't share atoms
- Absorption of light by atoms

Solar energy

- We'd need to cover 1/3 of U.S. in 2050 w/solar panels to meet demands (3 students)
- Solar panels would fill Texas to power U.S. in 2008 (3 students)
- Wind energy = solar energy (wind driven by solar heating) (2 students)
- Solar energy comes from the sun
- Google and Walmart use solar energy

- Solar power generates 18 terawatts
- Energy from the sun is abundant
- Solar energy = clean, renewable energy

Solar technology

- Solar cells convert solar energy to electricity (4 students)
- It takes 4 yrs to get return on investment for traditional solar cells while with dye-sensitized it could take only 3 months (3 students)
- Dye-sensitized solar cells could be more affordable, durable, and get a return on investments in 3 months compared to 4 years.
- Solar electric power plants
- Photovoltaic solar cells can solve energy crisis
- Solar panels can save money but cost so much to make (2 students)
- Solar collectors heat water
- Solar panel is based on wavelength of light
- Silicon solar cells: Light w/energy greater than the band gap energy of Si is absorbed, energy is given to an electron, excites the electron and it is free to move, positive hold left in electrons place, separation of electrons and holes create s a current and charge.
- Dye-sensitized cell: Light with high enough energy excites electrons in dye molecule, excited electrons infused into semiconductor TiO_2, transported out of cell.

Other

- **Richard Smalley discovered the buckyball** (5)
- Richard Smalley was a chemist and got the Nobel prize (3 students)
- The world has less than 5% of the world's population!

Appendix E: Questions or statements of confusion submitted by students in the environmental science class on the Fine Filters Unit

(Ideas mentioned by 5 or more students are highlighted in bold)

Science

- Water = life; ¿porque muy es importante?
- Why is the proton and charge mixed together is +1?
- What is the charge of a neutron?
- Are there some people that are made of more or less than 70% of water?
- What do the δ^+ and δ^- mean?
- Why is chemistry so hard?
- What does the electron keep doing constantly?
- Water in the atmosphere helps keep the planet warm. How?
- What is a dipole?
- Which atom is positive? Negative? [In reference to the water molecule.]
- What does valence mean?
- Why is salt water so bad?
- How much fluoride does it take before it becomes toxic?
- If it can cause those kinds of affects then why do we add the fluoride to the water?

Technology

- Can we ever use the ice cap water?
- If so much fresh water is frozen as glaciers, and the glaciers are allegedly melting, then why can't that fresh water in whole or in part be captured as drinking water?
- Can we get fresh water from saline water?

Distribution and Use of Fresh Water

- How can the UK use less water than us? (2 comments)
- Why don't they [the UK] have a lot of agriculture?
- Where does all the contaminated drinking water come from?
- Why 1 percent available [fresh water]?
- Population increase will expand the water demand.

Water crises should be more of an issue

- **Why is it that the water crisis isn't a big issue in the world today?**
- Where is the water crisis more of an issue?
- What is the government doing to help this issue?
- What are some possible reasons for the end of the world?
- Why don't the wealthy water places share water with the poor places? Ex: US getting some water to Africa.
- How much longer until we run out of water?
- Approximately how much fresh water do we have?

Appendix F: Aha or wow statements submitted by students in the environmental science class on the Fine Filters Unit

(Ideas mentioned by 5 or more students are highlighted in bold)

Water distribution

- Our planet is 70% water. (2 comments)
- planet = 70% water; bodies = 70% water (3 comments)
- 20% lack fresh clean water (3 comments)
- **2.4 billion people are living in high water stressed areas** (10 comments)
- 1.4 billion people lack clean drinking water
- less than 1% is obtainable fresh water (lakes, etc)
- most fresh water is in ice caps, glaciers & ground water
- very little water is available for drinking
- Ground water is 30.0% of the safe water
- The rest in icecaps, & glaciers, 68.7%; rivers 2% swamps 11%, lakes 87%
- **Less than 3% of the earth's water is fresh.**
- The water in China and Mexico isn't clean

Water use

- Water is needed for life. No water = no life. (2 comments)
- billions of tons of water to make one burger and a glass of milk
- residential water use has doubled since 1980
- Mexico has 100+ purchasing power, but they use 350+ liters of water per person

The lack of clean drinking water

- **7 million die yearly from diseases caused by unclean water.**
- A lot countries have bad and polluted water
- lack of water systems infrastructure
- no access to clean water without disease
- 80% of child death under age 5 - die of unsafe water

Sanitation and other sources of pollution

- **2.6 billion lack access and sanitation systems that separate sewage**
- 40% of the world's population lack sanitation systems
- sewage from drinking water
- sewage most common pollution
- pesticides and fertilizers levels
- industrial water dumping
- arsenic and fluoride levels

Science

- Water atoms are composed of a nucleus, neutrons and protons, and electron cloud
- High surface tension lets it to adhere.
- Specific heat is amount of energy required to change 1 gram of a substance 1^{o} C.
- Electrons are negatively charged
- Electrons are always moving around

- Bonds are formed because + attract
- An electron cloud is composed of electrons
- Electronegativity is a term describing relative ability of an atom when bonding electrons to itself
- Valence; electronegativity, water is a universal solvent, water has high surface tension
- The nucleus cloud is found in an electron
- Electronegativity: ability to attract bonding; hydrogen's electron spends more time closer to oxygen's nucleus; electric density more at the oxygen
- Saline=salt
- too much fluoride effects your bones negatively

General

- Everything was interesting!
- This is cool.
- population 2050 - 9 billion people WOW!!!
- In poverty, 1 in 3 people live on 1$/day impacting on health, relocation, and the economy
- There are many causes of the water crisis: climate and geography, lack of water systems and infrastructure, inadequate sanitation
- As the population increases the water shortage increases