Engaging Preservice Secondary Science Teachers in a NGSS-Based Energy Lesson: A Nanoscience Context

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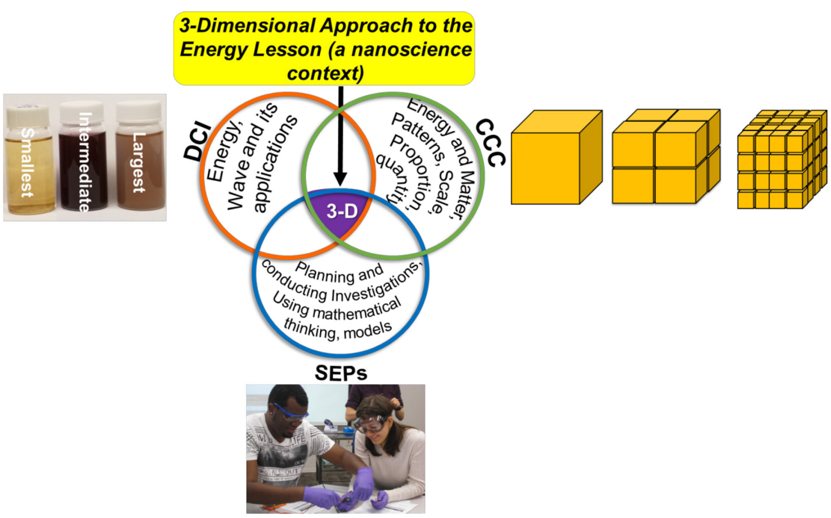
ABSTRACT

The new approach to teaching science presented by Next Generation Science Standards (NGSS) warrants trained high-quality science, technology, engineering, and mathematics (STEM) teachers to prepare the future STEM workforce. We share the implementation of an energy lesson using a *nanoscience* approach, well-aligned with the NGSS vision, in a secondary STEM education course for preservice science teachers. First, we engaged preservice teachers in discussions related to alternate sources of energy followed by the case study approach to illustrate a real-world problem of energy deficiency and solar energy (solar cells using nanoparticles) as one potential solution because it is cost-efficient, clean, and a renewable source of energy. Preservice teachers conducted several hands-on explorations in groups using real cube-models to understand and illustrate the size-dependent nature and dimensions of nanoparticles, used lasers and visuals of a UV–vis spectrum, and observed the trends in voltage and current outputs for fluorine-doped tin oxide electrodes with and without nanoparticle solution. Formulating evidence-based explanations, students summarized their findings as a case study report regarding the nanoparticle approach as a remedy to the energy deficit problem. The lesson provides opportunities for preservice science teachers to develop an understanding of green energy as well as illustrating how the NGSS standards are tied together in a science lesson.

GRAPHICAL ABSTRACT



KEYWORDS

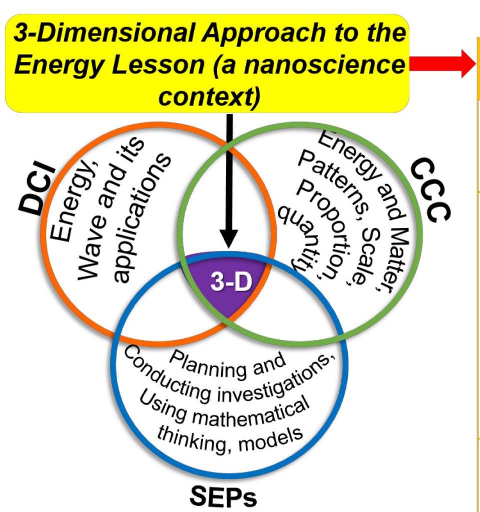
Continuing Education, Laboratory Instruction, Hands-On Learning/Manipulatives, Materials Science

INTRODUCTION

Understanding energy and its fundamental laws is an integral part of the school curriculum across disciplines. Despite its significance, K–12 students are often not exposed to practical applications of clean and renewable (alternative sources) energy and *how* they work to meet the growing energy demand around the world.[1,2] One such alternative source of energy is the use of nanoparticles that inquires remedy to the energy deficit problems especially light harvesting (make efficient solar cells).[3,4] Scientists and educators across the globe have recognized nanoscience education as an inspiring field offering exciting new phenomena, unseen mysteries, and a spectrum of globally relevant applications.[5,6]

Most recently, the Next Generation Science Standards[7] (NGSS) presents the three-dimensional approach to science learning that includes the following constructs: disciplinary core ideas (DCI), cross-cutting concepts (CCC), and science and engineering practices (SEP). While the new vision for science learning has been emphasized by the NGSS, there are limited resources and models available for science teacher educators to support prospective science teachers in this endeavor. Preparing *high-quality science teachers* during their teacher preparation programs is warranted for them to execute NGSS-based learning in their future classrooms. Herein, we describe a NGSS-based energy activity designed for a science, technology, engineering, and mathematics (STEM) education methods course for prospective secondary science teachers (referred to as students hereafter). The overall goal of the methods course was to familiarize preservice teachers with appropriate methods of teaching science and engineering in secondary science classrooms. The lesson, laboratory experiment, and the associated activities were designed for preservice teachers to experience NGSS and its three dimensions in action for them to be able to develop skills to design their own NGSS-based science lessons in the future. Although this is not the complete unit but a tool to build upon, we contend that the lesson and associated activities will serve as an example for college faculty to train future STEM teachers to meet the new NGSS standards while developing a basic understanding of nanoscience.

While this project has two parts—a laboratory experiment and a discussion on the pedagogical principles that aligns well with the three dimensions of the NGSS—instructors may choose the laboratory activity and/or subparts of the associated activities in a college general chemistry or nonmajors chemistry and physics courses. The activities described can also be used as a part of professional development opportunities for inservice STEM teachers or college STEM faculty to understand the connections between science topics and pedagogical principles (aligned with NGSS). The laboratory activity can be used in high school chemistry courses as well. In the literature, nanoparticle synthesis and characterization has been used to develop an understanding of size dependent optical properties and applications, which include sensing, catalysis, and energy conversion.[8–16] Here, we focus on nanoparticles (NP) and their applications to energy to line up as the DCI. The CCCs are: (i) patterns; (ii) scale, proportion, and quantity; and (iii) energy and matter. The SEPs include planning and carrying out various investigations, and using real wooden cube models and mathematical thinking to understand the size-dependent behavior of nanoparticles (Figure 1).[13,17–20] The details on the NGSS connections to the three dimensions are provided in the Supporting Information.



3-Dimensions of NGSS	3-Dimensional Approach to the Energy Lesson
DCI	Understanding NPs use in energy application. (Energy: HS-PS3.D; Wave and its Applications: HS-PS4.B)
CCC	i) Patterns – Students will use geometry to understand dimensional effects on NP interaction with light. ii) Scale, proportion and quantity – Use of surface-to-volume ratio to recognize how size-dependent behavior of nanoparticle allows storing more light energy (solar cells). iii) Energy and matter – Enhanced light matter interactions make NPs important for energy applications.
SEPs	i) Planning and conducting investigations. ii) Using models and mathematical thinking– Students use real wooden cube models to calculate surface-to-volume ratio.

Figure 1. The three-dimensional approach to the energy lesson.

THE CONTEXT

The activity was implemented in a STEM education course designed for STEM secondary education majors who aim to teach science at the secondary or high school level. The class met three times a week, for a 50 min per class period over the course of a 16-week semester. The course was structured as a combined lecture–laboratory format, wherein students participated in various hands-on inquiry-based investigations, collaborative teamwork, and group discussions. There were 27 students enrolled, 10 were secondary mathematics education majors, and 17 were science majors from various science disciplines (biology, chemistry, and earth and space science). For all the activities discussed below, students were divided into 6 groups of 4, and 1 group of 3. This activity was completed in one week (three class periods). The description and list of activities per class period is given in Table 1. In class, students worked in groups to conduct hands-on investigations and to collect and analyze their data to generate findings based on evidence and reasoning. Students then wrote an individual report to present their findings. Below we report the systematic procedure to describe the activity, investigations, and the final report.

Table 1. Gold Nanoparticle Activities and Their Component Descriptions by Class Period

Class	Activity	Description
1	Part 1: Motivation and case study approach	Introduction to the NGSS and the three-dimensional approach to science learning. Prior knowledge on energy and nanoscience was discussed.
		The history of nanoscience was introduced, followed by the focus question and the case study scenario.
		Students conducted mathematical investigations by calculating the size-dependence (surface to volume ratio) using wooden cubes of varying sizes.
2	Part 2: Size-dependent nature of nanoparticles	Students were given 3 vials of gold nanoparticles and a 532 nm laser. They recorded the appearance of the solution before and after shining the laser through the solution.
	Part 3: Experimental set-up (preparation of solar cell)	Students were provided with two solar cells: one with nanoparticles and another without nanoparticles. They compared the voltage and current outputs between the two electrodes.
3	Part 4: The results	Students discussed the absorption spectrum of the three nanoparticle solutions (handout) to develop evidence-based reasoning from their experimental data from earlier explorations.
		Discussion on the alignment of the lesson in terms of DCI, CCC, and SEPs, and integrating science, mathematics, creativity in one lesson.

PROCEDURE

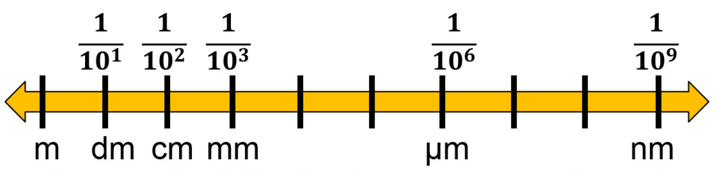
Part 1: Motivation and the Case Study Approach

We began the lesson by engaging preservice teachers in a discussion of the NGSS standards and the three dimensions. After the discussion, each individual student visited the online NGSS website[7] to get further familiarity with the standards. We then began our science lesson for students to make connections with how the lesson aligns with the NGSS. The lesson began by addressing the whole class, and asking questions to gain information about students' prior knowledge of energy. For example, we asked, "What are the examples for renewable and non-renewable sources of energy?" Then, we used the case study method to pique students' interest in the topic of energy. Case studies are often stimulating as they allow students to "*think and act like scientists"* to solve a real-world problem.[21] This case focused on solving the energy deficit by using solar energy (solar cells using nanoparticles) because it is a cheaper, cleaner, and a renewable source of energy. We proposed the following scenario along with a focus question (see the Supporting Information):

> Your school is a strong advocate of green energy and cutting energy consumption and cost, for which they need funding from the state to

> change inefficient light bulbs to light-emitting diodes (LEDs) and install solar panels. So, you are required to submit a justification/report explaining why and how solar panels (a nanotechnology approach) are a better option. **Focus question:** What makes nanoparticles an efficient component in renewable energy applications?

After presenting the scenario, we asked questions to assess students' background knowledge about nanoscience. For example, we asked, "What do you know about nanoscience?" While many students shared applications of nanotechnology they had heard of such as sensors, nano computers and so on, they struggled to share what "nano" meant to them. Often times, students struggle to conceptualize the size as small as a nanometer (10^{-9} meters) and that of a nanoparticle. Therefore, we used several everyday examples for students to develop a perspective for a nanoscale, for instance: "How does the height of an average human being compare to the diameter of a human hair?", or "How does the diameter of a human hair compare to the size of a water molecule?" We then introduced a number line (see Figure 2) and conversion items for students to interpret and use the nanoscale.



Convert the following into corresponding units

1 cm	=	m
1 nm	= ______________	m
1 nm	= ______________	cm

Figure 2. The number line showing meter-to-nanometer conversion.

During whole-group discussions, we realized that students perceived nanoscience applications as fairly new. We therefore presented historical evidences for the use of nanoparticles deep-rooted in ancient times (without being known as nanoparticle/nanoscience then). We discussed the use of nanoparticles in the 4th century BCE by glass blowers where metal nanoparticles of silver and gold were embedded in glass chalices and stained-glass windows to impart color. In Ayurveda (an ancient Indian system of medicine), metals were used as a form of treatment called *Bhasma*[22] (a concoction of metal and herbal juice producing biologically active nanoparticles).[23,24] At the 95th Indian Science Congress, Dr. Robert Curl, Nobel Laureate in 1996 for the discovery of Buckminster fullerene, "nano" carbon, brought to light that blacksmiths from southern India manufactured daggers used by warriors by reinforcing iron with carbon to enhance sharpness and strength, akin to the Damascus sword.[25]

Part 2: Size-Dependent Nature of Nanoparticles

Each student group was engaged in hands-on activities to understand the size-dependent nature[26] and dimensions of nanoparticles. They were provided wooden cubes (see Figure 3) with varying sizes (example, cubes with side length as 2 in., 1 in., and 0.5 in.) and were asked to calculate the total surface-to-total volume ratios in each case. The data recording sheet is available in the Supporting Information. Students noted patterns in the data and found that the smaller the size of the cube, the larger the total surface-to-total volume ratio.

During the whole-group discussions, we explained that as the dimensions of the nanoparticle become smaller, they begin to absorb light due to increased surface-to-volume ratios and its electronic structure,[27,28] unlike in synthetically manufactured organic dye molecule, where nanoparticles can absorb only a smaller wavelength range or energy of incident light. The concept of increasing surface-to-volume ratio was used to correlate the changes that take place when bulk gold (Au) transitions to a nanoparticle Au→AuNP.[29,30] This concept of size-dependent absorption behavior was further developed through experiments described below.

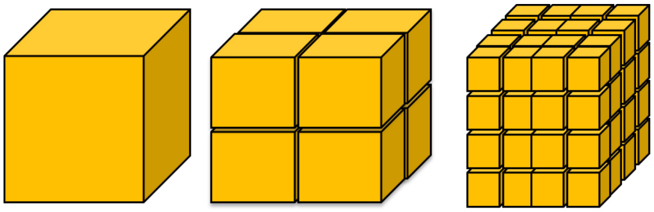


Figure 3. Cube model showing increased surface-to-volume ratio in nanoscale material.

Part 3: Experimental Set-Up—Preparation of Solar Cell with AuNP

Metal nanoparticles discussed in this activity are made of gold (AuNP). AuNPs have a property called surface plasmon resonance, which is the oscillation of electrons due to perturbations (absorption) caused by light. This light–matter interaction makes AuNPs important for energy applications because of their capacity to absorb light over a range of energies in the electromagnetic spectrum.[31] AuNPs also have the capacity of promoting electron transfer needed for current generation. From the literature, it is evident that when AuNPs are coupled with titanium dioxide, they produce photocurrent.[32,33]

Synthesis of Gold Nanoparticles. All chemicals were purchased from Sigma Aldrich. The Turkevich method was followed for the synthesis of colloidal gold (intermediate and largest size).[34,35] For the 1 nm (smallest) AuNP solution, a literature procedure was used.[36] Details of the syntheses are in the Supporting Information.

Size Dependence and Color. Each student group was provided with premade samples of three nanoparticle solution vials of three different sizes made from the gold salt (Figure 4). Students observed and recorded the appearance of the gold nanoparticle solutions (Figure 4) using key words such as transparent, intermediate, or opaque (the sample data recording work sheet is available as the Supporting Information). Students observed that the opaque sample containing the largest AuNP particles scattered light and showed a dichromatic effect of purple when light is transmitted and orange when light is scattered. The intermediate solution absorbed a little light and the solution was denser than the transparent sample (semitransparent). In the transparent sample (smallest AuNP particles), students could see the light transmit clearly. This is because of the absence of Mei scattering, as there were no large particles in the sample.[37]

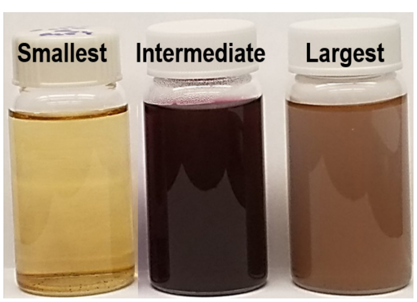


Figure 4. Gold nanoparticle solutions with particle sizes of 1–100 nm used for analysis.

Then, students were provided with lasers (a 532 nm laser pointer, green wavelength) and were asked to observe the trends in color change when the laser passed through each of the solutions. The largest sample did not show any change, the intermediate sample absorbed some of the light but the change was not clearly seen with the naked eye, and the students could quantify the difference in opacity from the largest sample vial. The smallest AuNP (~1 nm) absorbed the 532 nm laser light and emitted red light. This is dictated by the surface-to-volume ratio, that is, the dimension or *geometry* of the nanomaterial.[38] We further discussed with the whole group that bulk gold/ornamental gold reflects light and is opaque. As the dimensions become smaller, smaller AuNPs with increased surface-to-volume ratios, when embedded in solar cells, will absorb more sunlight. Based on the above observations, students concluded that the smallest AuNP solution will be best suited for making the solar cell, thus making AuNPs excellent material for energy applications, namely light harvesting.[32,39,40] Therefore, for constructing a working solar cell the smallest AuNP (~1 nm diameter) solution was the only one used. The procedure is given below.

Preparation of the Electrodes. The solar cell was constructed based on literature procedures.[32] The fluorine-doped tin oxide (FTO) electrodes were purchased from Hartford glass; details of the product are given in the Supporting Information. They were precut to 1 in. dimension squares. These FTO electrodes were sonicated with acetone and ethanol before they were used. Then TiO_2 paste ordered from Solaronix was coated on the conductive side. This was then heated on a hotplate to remove any organic material. On cooling this electrode, a layer of gold nanoparticle solution was added dropwise. To the second FTO electrode, carbon was deposited from soot to make electrical contact. The two electrodes were then held together via a binder clip. This assembly was given to students to add the electrolyte. The electrolyte used was 1M potassium iodide in water. When students were ready to measure the current being generated with and without nanoparticles, they used alligator clips to connect to a multimeter and then they recorded the current in ohms. (See Figure 5.) Details are in the Supporting Information. Alternatively, a commercially available kit can be used for this purpose; details are also available in the Supporting Information.

Part 4: The Results

Each student group measured and compared the changes in voltage and current outputs for the two FTO electrodes (Figure 5), one with AuNP solution (~1 nm samples only), and the other without AuNP using three trials. (See the Supporting Information for the data recording sheet.) Results showed that the solar cell with AuNP exhibited higher levels of voltage (4.6 mV) as compared to the solar cell without AuNP (1.3 mV). The higher levels of voltage generation are only possible in the solar cell coated with the ~1 nm AuNP solution because it can absorb a higher quantity of UV and visible radiation.

Figure 5. Students measuring photocurrent using ~1 nm AuNP solution coated FTO electrodes.

To reinforce this idea that the ~1 nm AuNP solution was the best choice for constructing a solar cell, each student group was provided a handout of the UV–vis spectrum generated by the instructor previously. Students can also generate their own spectrum using a handheld UV–vis spectrophotometer, directions are given in the Supporting Information. This spectrum was collected from the three nanoparticle solutions that students used in the laser exercise. From the UV–vis spectrum (Figure 6), students observed the variations in the profile: the wavelengths of absorption were 300–900 nm for the smallest sample. Second, they observed that as the size of the particle increases, the background signal increased (i.e., the absorption value did not begin at zero at 900 nm). This indicates greater scattering than absorption for larger diameter nanoparticles. Additionally, the red-shift in the absorption maximum (from 538 nm to 582 nm) is also indicative of the larger size of the nanoparticle. For the smallest AuNP particle, which is ~1 nm, the UV–vis spectrum showed the characteristic peak at 670 nm and higher absorption below 450 nm.

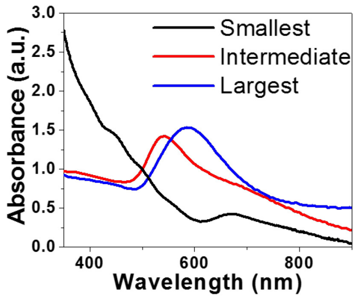


Figure 6. Absorption spectrum of the nanoparticles used in this experiment.

HAZARDS AND SAFETY PRECAUTIONS

Before beginning the activity, students must wear chemical resistant safety goggles at all times to prevent splashes. All chemicals and glassware should be handled with chemical resistant gloves. All glassware, such as disposable pipettes and FTO electrodes, are disposed of in glass disposal and/or a solid waste container, and liquids into a designated liquid waste container. Coating of FTO electrodes and heating them on hotplates should be done in the fume hood. Similarly, using an open flame to coat carbon soot should be done in a hood with heat resistant gloves on. In case of an accident, students should be instructed to notify the instructor for immediate assistance. In this experiment, the electrodes and AuNP solutions were premade by the project directors.

DISCUSSION: THE NGSS CONNECTIONS

Considering the overall goal of the lesson is to help preservice teachers understand how the NGSS and the three dimensions are applied to a science lesson, we engaged student groups in a rich discussion to illustrate the DCI, CCC, and SEPs used in the lesson. To begin the discussion, each group was provided a blank handout of Figure 1 for them to brainstorm, and write what DCI, SEPs, and CCC they think were the focus of the nanoscience lesson. The goal of this activity was to allow preservice teachers to identity how the science activities aligned with the three dimensions of the NGSS. For each of the SEPs and CCCs the students identified, they were asked to provide examples from the activities they had completed. For instance, a group of students identified “use of models” as a SEP and justified the use of cube models to understand the dimensions of nanoparticles. When each group was ready with their completed handout we asked questions such as, “What crosscutting concepts were used in the lesson, and how?” and “What scientific practices were utilized in the lesson, and how?” Most student responses included “energy and matter” as the cross-cutting concept and “planning and carrying out investigations”.

After the discussion on how the activities aligned with the pedagogical principles as suggested by NGSS in terms of DCI, CCC, and SEP connections, we provided the handout of Figure 1. We discussed additional CCCs such as patterns and scale, proportion, and quantity to illustrate the use of real cube models to understand the size-dependent behavior of nanoparticles. Similarly, we discussed additional scientific practices used in the lesson, such as the use of models and mathematical thinking with real wooden cube models to calculate surface-to-volume ratio. In summary, this lesson offered ample opportunities for preservice teachers to deepen their understanding of energy in a nanoscience context through a collaborative learning experience as well as developing a shared understanding of NGSS in action. Although we are aware that the energy conversion is not the best that is experimentally reported, after all the evidence from investigations, and used only as a demonstration of the concept, students were able to put together their case study reports providing justification of use of nanoparticles in solar cells as an effective source of energy.

CONCLUSIONS

The overall goal of the lesson was to develop a clear understanding of the alignment of the NGSS and its dimensions within a science lesson. Based on this goal, we had students complete an online open-ended questionnaire outside of class as a pre- and posttest to share their views on their familiarity with the standards and how confident they feel designing science lessons to align with the standards. Figure 7 shows that a majority of students were familiar with the NGSS standards at the end of the lesson. At the end of the laboratory activity nearly 69% of all students indicated greater familiarity with the NGSS than before, where only 11% reported being familiar with it. The open-ended responses are in line with the aforementioned trends of the survey results; many students shared how engaging in the lesson promoted their understanding of the NGSS:

> *"We did a lot of hands on activities in this class. I loved the 3D model and the practices. I can definitely see using those strategies when I am a teacher"*. [Student 1]

> *"From a student perspective I did not even realize that I was covering these standards just by the nanoparticle experiment. Then later, I got to see like oh! these three standards* [referring to the three dimensions: DCI, CCC, SEPs] *were covered during this section."* [Student 2]

> *"I thought it was really interesting especially the 3D model. It was just again a very unique experience because I've never had to work with the NGSS standards. We got to the energy lesson to work with the NGSS standards. We had a worksheet that we had to go through and do a scavenger hunt to find the standard* [referring to DCI, CCC, SEPs] *for our science lesson."* [Student 3]

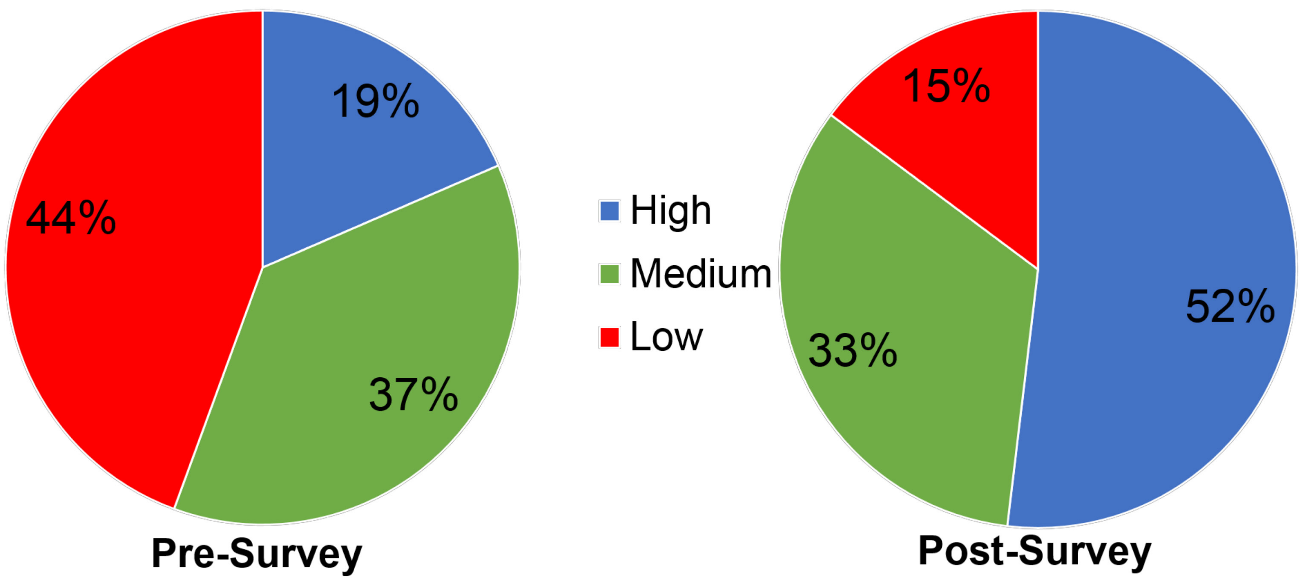


Figure 7. Percentage of students (*n* = 27) who reported their familiarity with the NGSS on a three-point scale: familiar, somewhat familiar, and not familiar.

In addition, Figure 8 shows an increase in the percentage of students who reported high confidence for designing NGSS-based science lessons on a three-point scale: low, medium, high.

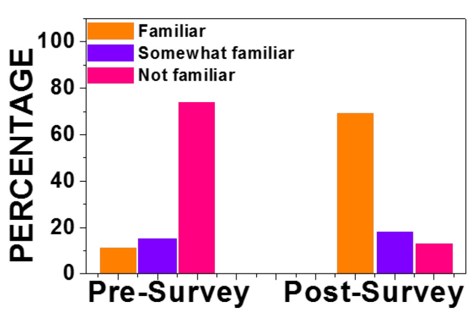


Figure 8. Percentage of students (*n* = 27) who reported their confidence to design NGSS based science lesson before (presurvey) and after (postsurvey) completing the lesson and associated set of activities.

In summary, this laboratory activity is unique as it blends a contemporary science topic (nanoscience) with the understanding of the NGSS. Thus, science methods courses should provide more opportunities early on for prospective teachers to develop a deeper understanding of standards and to use the three dimensions in structuring their own lessons.

ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available on the ACS Publications website at DOI: 10.1021/acs.jchemed.

Details of experimental set-up and lesson plan and worksheets (DOCX)

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REFERENCES

(1) Asif, M.; Muneer, T. Energy Supply, Its Demand and Security Issues for Developed and Emerging Economies. *Renew. Sustain. Energ. Rev.* **2007**, *11*, 1388–1413.

(2) Kamat, P. V. Meeting the Clean Energy Demand: Nanostructure Architectures for Solar Energy Conversion. *J. Phys. Chem. C* **2007**, *111*, 2834–2860.

(3) Neder, V.; Luxembourg, S. L.; Polman, A. Efficient Colored Silicon Solar Modules Using Integrated Resonant Dielectric Nanoscatterers. *Appl. Phys. Lett.* **2017**, *111*, 073902.

(4) Zahn, M. Magnetic Fluid and Nanoparticle Applications to Nanotechnology. *J. Nanopart. Res.* **2001**, *3*, 73–78.

(5) Greenberg, A. Integrating Nanoscience into the Classroom: Perspectives on Nanoscience Education Projects. *ACS Nano* **2009**, *3*, 762–769.

(6) Jackman, J. A.; Cho, D.-J.; Lee, J.; Chen, J. M.; Besenbacher, F.; Bonnell, D. A.; Hersam, M. C.; Weiss, P. S.; Cho, N.-J. Nanotechnology Education for the Global World: Training the Leaders of Tomorrow. *ACS Nano* **2016**, *10*, 5595–5599.

(7) National Research Council. *Next Generation Science Standards: For States, By States;* National Academies Press: Washington, DC, 2013; https://www.nextgenscience.org/ (accessed Dec 2018).

(8) Smestad, G. P.; Gratzel, M. Demonstrating Electron Transfer and Nanotechnology: A Natural Dye-Sensitized Nanocrystalline Energy Converter. *J. Chem. Educ.* **1998**, *75*, 752.

(9) Zemke, J. M.; Franz, J. A Biphasic Ligand Exchange Reaction on CdSe Nanoparticles: Introducing Undergraduates to Functionalizing Nanoparticles for Solar Cells. *J. Chem. Educ.* **2016**, *93*, 747–752.

(10) Cea, P.; Martín, S.; González-Orive, A.; Osorio, H. M.; Quintín, P.; Herrer, L. Nanofabrication and Electrochemical Characterization of Self-Assembled Monolayers Sandwiched between Metal Nanoparticles and Electrode Surfaces. *J. Chem. Educ.* **2016**, *93*, 1441–1445.

(11) Markina, N. E.; Pozharov, M. V.; Markin, A. V. Synthesis of Copper(I) Oxide Particles with Variable Color: Demonstrating Size-Dependent Optical Properties for High School Students. *J. Chem. Educ.* **2016**, *93*, 704–707.

(12) Jenkins, S. V.; Gohman, T. D.; Miller, E. K.; Chen, J. Synthesis of Hollow Gold–Silver Alloyed Nanoparticles: A "Galvanic Replacement" Experiment for Chemistry and Engineering Students. *J. Chem. Educ.* **2015**, *92*, 1056–1060.

(13) Jenkins, J. A.; Wax, T. J.; Zhao, J. Seed-Mediated Synthesis of Gold Nanoparticles of Controlled Sizes To Demonstrate the Impact of Size on Optical Properties. *J. Chem. Educ.* **2017**, *94*, 1090–1093.

(14) Njagi, J.; Warner, J.; Andreescu, S. A Bioanalytical Chemistry Experiment for Undergraduate Students: Biosensors Based on Metal Nanoparticles. *J. Chem. Educ.* **2007**, *84*, 1180.

(15) Raghuwanshi, V. S.; Wendt, R.; O'Neill, M.; Ochmann, M.; Som, T.; Fenger, R.; Mohrmann, M.; Hoell, A.; Rademann, K. Bringing Catalysis with Gold Nanoparticles in Green Solvents to Graduate Level Students. *J. Chem. Educ.* **2017**, *94*, 510–514.
(16) Feng, Z. V.; Lyon, J. L.; Croley, J. S.; Crooks, R. M.; Vanden Bout, D. A.; Stevenson, K. J. Synthesis and Catalytic Evaluation of Dendrimer-Encapsulated Cu Nanoparticles. An Undergraduate Experiment Exploring Catalytic Nanomaterials. *J. Chem. Educ.* **2009**, *86*, 368.
(17) Zhang, X.; Wang, Z.; Xu, C. Demonstrating the Many Possible Colors of Gold-Supported Solid Nanoparticles. *J. Chem. Educ.* **2015**, *92*, 336–338.
(18) Sharma, R. K.; Gulati, S.; Mehta, S. Preparation of Gold Nanoparticles Using Tea: A Green Chemistry Experiment. *J. Chem. Educ.* **2012**, *89*, 1316–1318.
(19) Frank, A. J.; Cathcart, N.; Maly, K. E.; Kitaev, V. Synthesis of Silver Nanoprisms with Variable Size and Investigation of Their Optical Properties: A First-Year Undergraduate Experiment Exploring Plasmonic Nanoparticles. *J. Chem. Educ.* **2010**, *87*, 1098–1101.
(20) Orbaek, A. W.; McHale, M. M.; Barron, A. R. Synthesis and Characterization of Silver Nanoparticles for an Undergraduate Laboratory. *J. Chem. Educ.* **2015**, *92*, 339–344.
(21) Herreid, C. F.; Schiller, N. A. Case Studies and the Flipped Classroom. *J. Coll. Sci. Teach.* **2013**, *42*, 62–66.
(22) Chaudhary, A. Ayurvedic Bhasma: Nanomedicine of Ancient India and Its Global Contemporary Perspective. *J. Biomed. Nanotechnol.* **2011**, *7*, 68–69.
(23) Pal, D.; Sahu, C. K.; Haldar, A. Bhasma: The Ancient Indian Nanomedicine. *J. Adv. Pharm. Technol. Res.* **2014**, *5*, 4–12.
(24) Duncan, K. A.; Johnson, C.; McElhinny, K.; Ng, S.; Cadwell, K. D.; Zenner Petersen, G. M.; Johnson, A.; Horoszewski, D.; Gentry, K.; Lisensky, G.; Crone, W. C. Art as an Avenue to Science Literacy: Teaching Nanotechnology through Stained Glass. *J. Chem. Educ.* **2010**, *87*, 1031–1038.
(25) Verhoeven, J. D.; Pendray, A. H.; Dauksch, W. E. The Key Role of Impurities in Ancient Damascus Steel Blades. *JOM* **1998**, *50*, 58–64.
(26) Guedens, W. J.; Reynders, M.; Van den Rul, H.; Elen, K.; Hardy, A.; Van Bael, M. K. ZnO-Based Sunscreen: The Perfect Example To Introduce Nanoparticles in an Undergraduate or High School Chemistry Lab. *J. Chem. Educ.* **2014**, *91*, 259–263.
(27) Varnavski, O.; Ramakrishna, G.; Kim, J.; Lee, D.; Goodson, T. Optically Excited Acoustic Vibrations in Quantum-Sized Monolayer-Protected Gold Clusters. *ACS Nano* **2010**, *4*, 3406–3412.
(28) Kim, J.; Lee, D. Size-Controlled Interparticle Charge Transfer between TiO_2 and Quantized Capacitors. *J. Am. Chem. Soc.* **2007**, *129*, 7706–7707.
(29) Jain, P. K.; Lee, K. S.; El-Sayed, I. H.; El-Sayed, M. A. Calculated Absorption and Scattering Properties of Gold Nanoparticles of Different Size, Shape, and Composition: Applications in Biological Imaging and Biomedicine. *J. Phys. Chem. B* **2006**, *110*, 7238–7248.
(30) Jin, R.; Zeng, C.; Zhou, M.; Chen, Y. Atomically Precise Colloidal Metal Nanoclusters and Nanoparticles: Fundamentals and Opportunities. *Chem. Rev.* **2016**, *116*, 10346–10413.
(31) Zhan, Z. B.; Grote, F.; Wang, Z. J.; Xu, R.; Lei, Y. Degenerating Plasmonic Modes to Enhance the Performance of Surface Plasmon Resonance for Application in Solar Energy Conversion. *Adv. Energy Mater.* **2015**, *5*, 7.
(32) Chen, Y.-S.; Choi, H.; Kamat, P. V. Metal-Cluster-Sensitized Solar Cells. A New Class of Thiolated Gold Sensitizers Delivering Efficiency Greater Than 2%. *J. Am. Chem. Soc.* **2013**, *135*, 8822–8825.
(33) Choi, H.; Chen, Y.-S.; Stamplecoskie, K. G.; Kamat, P. V. Boosting the Photovoltage of Dye-Sensitized Solar Cells with Thiolated Gold Nanoclusters. *J. Phys. Chem. Lett.* **2015**, *6*, 217–223.
(34) Turkevich, J.; Stevenson, P. C.; Hillier, J. A Study of the Nucleation and Growth Processes in the Synthesis of Colloidal Gold. *Discuss. Faraday Soc.* **1951**, *11*, 55–75.
(35) Turkevich, J. Colloidal Gold. Part I. *Gold Bulletin* **1985**, *18*, 86–91.
(36) Devadas, M. S.; Bairu, S.; Qian, H.; Sinn, E.; Jin, R.; Ramakrishna, G. Temperature-Dependent Optical Absorption Properties of Monolayer-Protected Au25 and Au38 Clusters. *J. Phys. Chem. Lett.* **2011**, *2*, 2752–2758.
(37) Graaff, R.; Aarnoudse, J. G.; Zijp, J. R.; Sloot, P. M. A.; de Mul, F. F. M.; Greve, J.; Koelink, M. H. Reduced Light-Scattering Properties for Mixtures of Spherical Particles: A Simple Approximation Derived from Mie Calculations. *Appl. Opt.* **1992**, *31*, 1370–1376.
(38) Devadas, M. S.; Kim, J.; Sinn, E.; Lee, D.; Goodson, T.; Ramakrishna, G. Unique Ultrafast Visible Luminescence in Monolayer-Protected Au25 Clusters. *J. Phys. Chem. C* **2010**, *114*, 22417–22423.
(39) Devadas, M. S.; Kim, J.; Sinn, E.; Lee, D.; Goodson III, T.; Ramakrishna, G. Unique Ultrafast Visible Luminescence in Monolayer-Protected Au25 Clusters. *J. Phys. Chem. C* **2010**, *114*, 22417–22423.

(40) Abbas, M. A.; Kim, T.-Y.; Lee, S. U.; Kang, Y. S.; Bang, J. H. Exploring Interfacial Events in Gold-Nanocluster-Sensitized Solar Cells: Insights into the Effects of the Cluster Size and Electrolyte on Solar Cell Performance. *J. Am. Chem. Soc.* **2016**, *138*, 390–401.