2019

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

Deepika Menon

Mary Sajini Devadas

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

Deepika Menon [1] and Mary Sajini Devadas [2]

1 Department of Physics, Astronomy, Geosciences, Towson University, Towson, Maryland, USA

2 Department of Chemistry, Towson University, Towson, Maryland, USA

Corresponding authors — D. Menon, email dmenon@unl.edu ; M.S. Devadas, email mdevadas@towson.edu

ORCID Deepika Menon: https://orcid.org/0000-0002-8652-7019

Abstract

The new approach to teaching science presented by the Next Generation Science Standards (NGSS) warrants training 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; this was followed by a case-study approach to illustrate a real-world problem of

Published in *Journal of Chemical Education* 96 (2019), pp. 528–534.
doi:10.1021/acs.jchemed.8b00169

Submitted March 8, 2018; revised December 12, 2018; published January 22, 2019.
Supporting Information follows the References.

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 and illustrates how the NGSS standards can be tied together in a science lesson.

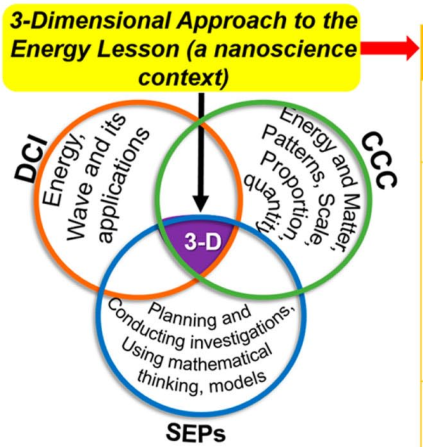
Keywords: Continuing Education, Laboratory Instruction, Hands-On Learning/Manipulatives, Materials Science

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) energy or 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, which can remedy energy-deficit problems, especially through light harvesting (i.e., making 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) present a 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). Although 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 an 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 the NGSS and its three dimensions in action so that they would be able to develop skills to design their own NGSS-based science lessons in the future. Although this is not a 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.

Although this project has two parts, a laboratory experiment and a discussion on the pedagogical principles that align well with the three dimensions of the NGSS, instructors may choose the laboratory activity or subparts of the associated activities in college general chemistry or nonmajor chemistry and physics courses. The activities described can also be used as a part of professional-development opportunities for in-service STEM teachers or college STEM faculty to understand the connections between science topics and pedagogical principles (aligned with the 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 (NPs) and their applications to energy to align with 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 NP use in energy applications. (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 ratios to recognize how size-dependent behavior of nanoparticles 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. Three-dimensional approach to the energy lesson.

Context

The activity was implemented in a STEM-education course designed for secondary-STEM-education majors who aim to teach science at the secondary or high-school level. The class met three times a week for 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 six groups of four and one group of three. This activity was completed in 1 week (three class periods). The descriptions and lists of activities for each class period are 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 individual reports to present their findings. Below, we report the systematic procedure to describe the activity, investigations, and 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	This was an 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.
2	Part 2: Size-Dependent Nature of Nanoparticles	Students conducted mathematical investigations by calculating the size dependence (surface-to-volume ratio) using wooden cubes of varying sizes.
	Part 3: Experimental Setup: Preparation of a Solar Cell with AuNPs	Students were given three 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.
		Students were provided with two solar cells: one with nanoparticles and another without nanoparticles. They compared the voltages and current outputs between the two electrodes.
3	Part 4: Results	Students discussed the absorption spectra of the three nanoparticle solutions (handout) to develop evidence-based reasoning from their experimental data from earlier explorations.
		A discussion on the alignment of the lesson in terms of DCI, CCC, and SEPs and integrating science, mathematics, and creativity in one lesson was conducted.

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, allowing 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 examples of 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 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?" Although many students shared applications of nanotechnology they had heard of, such as sensors, nanocomputers, and so on, they struggled to share what "nano" meant to them. Often times, students struggle to conceptualize sizes as small as a nanometer (10^{-9} meters) and the size of a nanoparticle. Therefore, we used several everyday examples for students to develop a perspective of the nanoscale; for instance, we asked, "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.

During whole-group discussions, we realized that students perceived nanoscience applications as fairly new. We therefore presented

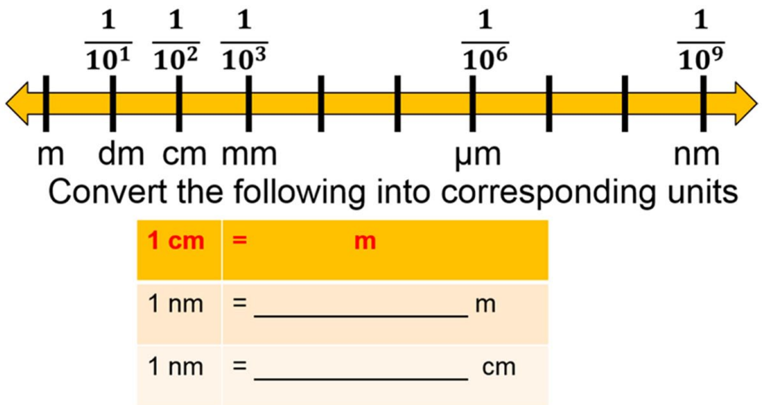


Figure 2. Number line showing meter-to-nanometer conversion.

historical evidence for the use of nanoparticles rooted in ancient times, although they were not known as nanoparticles or nanoscience at the time. We discussed the use of nanoparticles in the fourth century BCE by glass blowers in which 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, the 1996 Nobel Laureate for the discovery of Buckminster fullerene or “nano” carbon, brought to light that blacksmiths from southern India manufactured daggers for warriors by reinforcing iron with carbon to enhance sharpness and strength, akin the practices used to make 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 with wooden cubes (see **Figure 3**) of varying sizes (e.g., cubes with side lengths of 2, 1, 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.

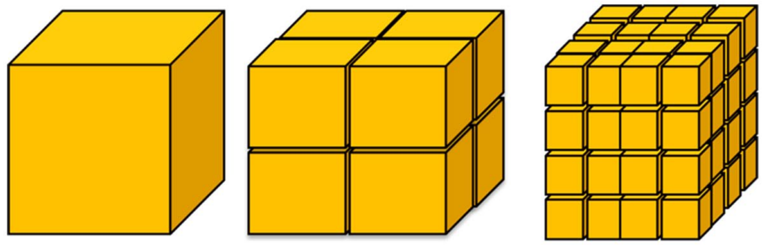


Figure 3. Cube model showing increased surface-to-volume ratios in nanoscale materials.

During the whole-group discussions, we explained that as the dimensions of the nanoparticle become smaller, they begin to absorb light because of the increased surface-to-volume ratios and the electronic structure,[27,28] unlike with synthetically manufactured organic dye molecules, in which nanoparticles can absorb only smaller wavelength ranges or the energy of incident light. The concept of increasing the 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.

Part 3: Experimental Setup: Preparation of a Solar Cell with AuNPs

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 sizes).[34,35] For the 1 nm (smallest) AuNP solution, a literature procedure was used.[36] Details of the syntheses are in the Supporting Information.

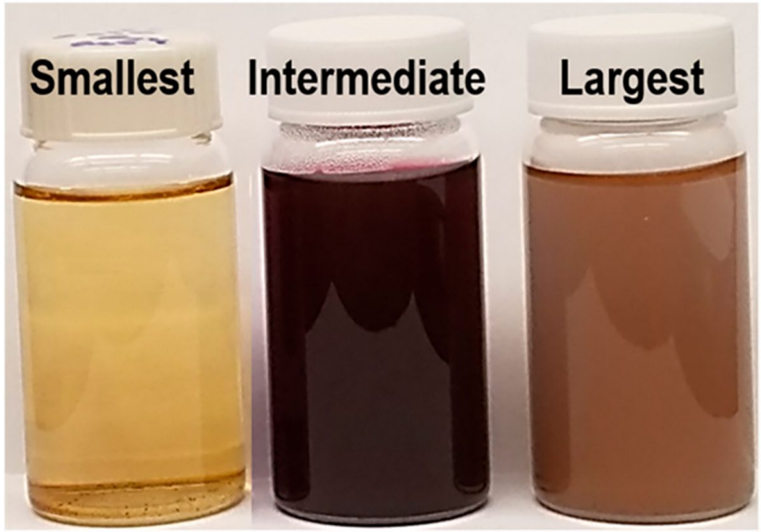


Figure 4. Gold-nanoparticle solutions with particle sizes of 1–100 nm used for analysis.

Size Dependence and Color. Each student group was provided with premade samples of three nanoparticle-solution vials of three different sizes made from gold salt (**Figure 4**). Students observed and recorded the appearances of the gold-nanoparticle solutions (Figure 4) using keywords such as transparent, intermediate, or opaque (a sample data-recording worksheet is available in the Supporting Information). Students observed that the opaque sample containing the largest AuNPs scattered light and showed a dichromatic effect of purple when light was transmitted and orange when light was scattered. The intermediate solution absorbed a little light, and the solution was denser than the transparent sample (semitransparent). In the transparent sample (smallest AuNPs), 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]

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 AuNPs (~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 and 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, absorb more sunlight. On the basis of the above observations, students concluded that the smallest AuNP solution would be best-suited for making the solar cell, thus making AuNPs excellent material for the energy application of 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 on the basis of 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 hot plate 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, who added the electrolyte. The electrolyte used was 1 M potassium iodide in water. When students were ready to measure the current being generated with and without nanoparticles, they used alligator clips to connect the setup 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: Results

Each student group measured and compared the changes in voltage and current outputs for the two FTO electrodes (Figure 5), one with the AuNP solution (~1 nm samples only) and the other without AuNPs, in three trials (see the Supporting Information for the data-recording

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

sheet). The results showed that the solar cell with AuNPs exhibited higher levels of voltage (4.6 mV) as compared with 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.

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 UV−vis spectra generated by the instructor previously. Students can also generate their own spectra using a hand-held UV−vis spectrophotometer (directions are given in the Supporting Information). These spectra were collected from the three nanoparticle solutions that the students used in the laser exercise. From the UV−vis spectra (**Figure 6**), students observed the variations in the profile: First, the wavelengths of absorption were 300−900 nm for the

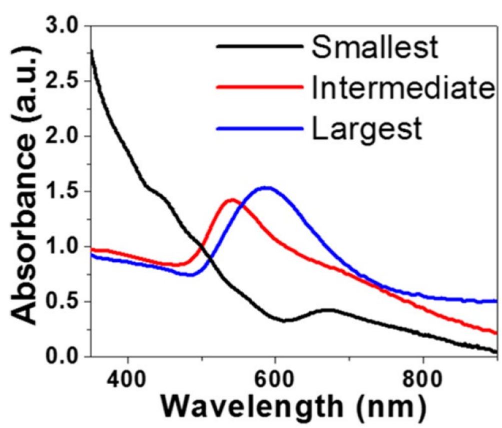


Figure 6. Absorption spectra of the nanoparticles used in this experiment.

smallest sample. Second, they observed that as the size of the particle increased, the background signal increased (i.e., the absorption value did not begin at 0 at 900 nm). This indicates greater scattering than absorption for larger-diameter nanoparticles. Additionally, a red-shift in the absorption maximum (from 538 to 582 nm) is also indicative of larger-size nanoparticles. For the smallest AuNPs (~1 nm), the UV− vis spectrum showed the characteristic peak at 670 nm and higher absorption below 450 nm.

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, should be disposed of in glass-disposal or solid-waste containers, and liquids should be disposed of in designated liquid-waste containers. Coating of FTO electrodes and heating of them on hot plates should be done in fume hoods. Similarly, using an open flame to coat carbon soot should be done in a hood with heat-resistant gloves. 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: 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 an 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 the 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 ratios. 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 and to develop a shared understanding of the NGSS in action. Although we are aware that the energy conversion that is experimentally reported is not the best, after all the evidence from investigations and through its use only as a demonstration of the concept, students were able to put together their case-study reports providing justification of the 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. On the basis of this goal, we had students complete an online, open-ended questionnaire outside of class as a pre- and post-test 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

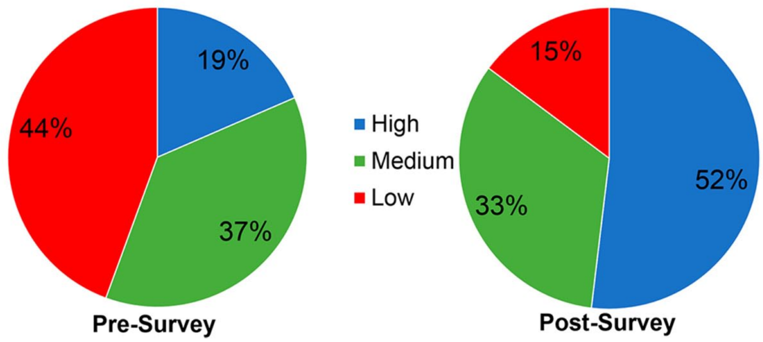


Figure 7. Percentage of students (n = 27) who reported their familiarity with the NGSS on a three-point scale: familiar, somewhat familiar, and not familiar.

activity, nearly 69% of all students indicated greater familiarity with the NGSS than before, whereas only 11% reported being familiar with it before. 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, and 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, and SEPs] for our science lesson.*
>
> Student 3

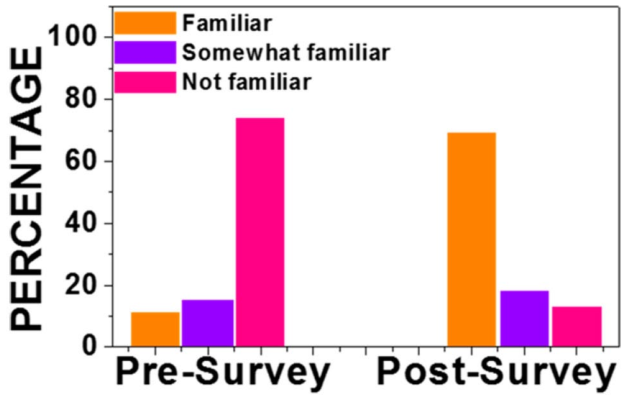


Figure 8. Percentage of students (n = 27) who reported their confidence in designing an NGSS-based science lesson before (presurvey) and after (postsurvey) completing the lesson and associated set of activities.

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, and high.

In summary, this laboratory activity is unique as it blends a contemporary science topic (nanoscience) with 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.

Supporting Information follows the References, including details of experimental setup, lesson plan, and worksheets.

Disclosures There are no competing financial interest to declare.

Acknowledgments The authors thank Sarah Talamantez-Lyburn for solution preparation. We thank Towson University's Faculty Development Research Committee grant and Fisher Endowment grants for funding. M.S.D. thanks the Fisher College of Science and Mathematics for the Fisher Endowed Chair award and NSF MRI 1626326.

References

(1) Asif, M.; Muneer, T. Energy Supply, Its Demand and Security Issues for Developed and Emerging Economies. *Renewable Sustainable Energy 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*, 1501654.

(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, T., III; 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.

Supporting Information

Engaging Preservice Secondary Science teachers in a NGSS-based Energy Lesson: A Nanoscience Context

Deepika Menon[*#1], Mary Sajini Devadas[*#2]

Towson University, Towson, MD.

[*1] Department of Physics, Astronomy, Geosciences, Towson University, Towson, MD 21252

[*2] Department of Chemistry, Towson University, Towson, MD 21252

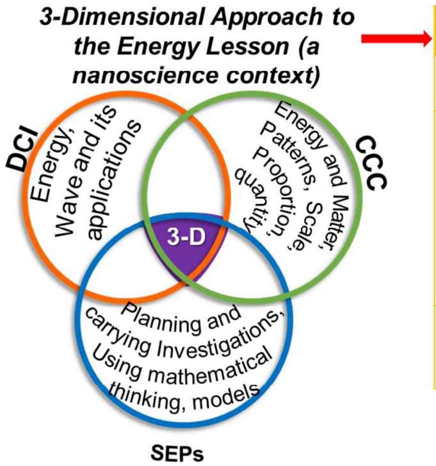
[#] Equal contribution

Corresponding authors: dmenon@towson.edu; mdevadas@towson.edu

Contents **Page No**

Contents	Page No
NGSS Connections	2
Calculation of surface-to-volume ratio	3
Synthesis of AuNP	5
Size Dependence and Color	7
Electrode Preparation	8
Measuring Voltage and Current	10
Case Study Report	11
Rubric	12

NGSS Connections



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 Carrying out investigations. ii) Using models and mathematical thinking– Students use real wooden cube models to calculate surface-to-volume ratio.

Fig. 1. The 3-Dimensional Approach to the Energy Lesson

Connecting to the Common Core State Standards (NGAC and CCSSO 2010)

This section provides the *Common Core* for English Language Arts and/or Mathematics standards and its connections to the energy lesson.

English/Language Arts: Grade 9-10

Writing Standards	**Connections to the Energy Lesson**
CCSS.ELA-LITERACY.W.9-10.1 : Write arguments to support claims in an analysis of substantive topics or texts, using valid reasoning and relevant and sufficient evidence.	• Students demonstrate their understanding of energy by writing their case study report that allows them to build an argument to support claims about energy crisis and the nanoparticle approach (solar panels) as one of the potential solutions.
CCSS.ELA-LITERACY.W.9-10.2 : Write informative/explanatory texts to examine and convey complex ideas, concepts, and information clearly and accurately through the effective selection, organization, and analysis of content.	• Students use appropriate information and examples to develop and write explanations of how and why nanoparticles are efficient sources of harnessing light (solar panels). This requires students to convey as well as organize their ideas clearly in their case study report write-up.

Mathematics Standards

Ratios & Proportional Relationships	**Connections to the Energy Lesson**
CCSS.MATH.CONTENT.6.RP.A.1 Understand the concept of a ratio and use ratio language to describe a ratio relationship between two quantities.	• Students calculate and use surface-to-volume ratio to describe the relationship and patterns with decreasing size of the cube. Students use ratio-reasoning to understand the patterns in the data.

Calculation of surface-to-volume ratio

Name: ________________ Date: _____________

Formulas to be used with explanation:

Length of one side of a cube = X inch

Surface area of square = X^2 $inch^2$

Surface area of cube = 6 * X * X = 6 X^2 $inch^2$

Volume of cube = X*X*X = X^3 $inch^3$

Instructions:

1. Calculate and record the parameters of the cube (provided in the table below).
2. Determine how many smaller cubes will make the large cube.
3. Recalculate and record the parameters for the smaller cubes.

Table 1: Calculation of surface-to-volume ratio

Side length of cube (inch)	**Surface Area of 1 Cube ($inch^2$)**	**Volume of 1 Cube ($inch^3$)**	**No. of Cubes to make one whole 2 inch cube**	**Total Surface Area ($inch^2$)** Hint: Surface Area of 1 Cube * No. of Cubes	**Total Volume ($inch^3$)** Hint: Volume of 1 Cube * No. of Cubes	**Surface-to-Volume ratio**

Data Analysis:

1. What pattern did you observe between the size of the cube and the change in total surface area?

2. What trend did you observe between the size of the cube and the change in total volume?

3. What trend did you observe between the size of the cube and surface to volume ratio?

4. What will happen to the surface to volume ratio if we decrease the size of the cube to the tiniest cube (atom) possible?

Results and conclusions:

Answers to table 1:

Side length of cube (inch)	**Surface Area of 1 Cube ($inch^2$)**	**Volume of 1 Cube ($inch^3$)**	**No. of Cubes to make one whole 2 inch cube**	**Total Surface Area ($inch^2$)** Hint: Surface Area of 1 Cube * No. of Cubes	**Total Volume ($inch^3$)** Hint: Volume of 1 Cube * No. of Cubes	**Surface-to-Volume ratio ($inch^{-1}$)**
2	24	8	1	24	8	24/8 = 3
1	6	1	8	6*8 = 48	8	48/8 = 6
0.5	1.5	0.125	64	1.5*64 = 96	64*0.125 = 8	96/8 = 12

Synthesis of AuNP

List of Material and reagents needed:

Goggles

Gloves

Hot plate

Hydrogen tetrachloroaurate(III)

Trisodium Citrate

Sodium borohydride

L-Glutathione

Methanol

Milli-Q water

Centrifuge

All glassware were cleaned using aquaregia before use and rinsed with MilliQ water. Briefly, for the synthesis a stock solution of hydrogen tetrachloroaurate (39 µmol) and trisodium citrate (85 µmol) were prepared in Milli-Q water. From the gold stock solution, 3 mL was taken and diluted to 20 mL by adding 17 mL of Milli-Q water in a 50 mL Erlenmeyer flask. Similarly, 5 mL aliquots of the gold stock solution were also diluted to 20 mL in another reaction vessels. Each of these solutions were brought to a gentle boil on a hot plate with stirring. To this boiling solution, 1 mL of the sodium citrate stock was added while stirring and boiling. Within a couple of minutes the solution changes color and begins to slowly turn from clear to a purple-like hue. At this point, the solutions are removed from the hotplate and set aside to attain room temperature before beginning analysis using lasers and UV-Vis spectrophotometer. The 1 nm gold solutions were synthesized using a published protocol using glutathione as the capping agent. A 3:1 thiol/gold molar ratio, and sodium borohydride reduction reaction held for 30 min at room temperature. For the preparation of 1 nm AuNP, to a vigorously stirred solution of 1.14 mmol

$HAuCl_4.3H_2O$ in 80 mL methanol was added 3.4 mmol of L-glutathione dissolved in 30 mL of water. The solution became colorless after 15 min, indicating Au (I) - thiol polymer formation. Then a solution of 11 mmol $NaBH_4$ was added with vigorous stirring. The solution immediately became black, indicative of MPC formation. Stirring was continued for another 30 min and then dried to produce a black product (as-prepared MPC). Pure 1 nm clusters were obtained by size fractionation using a 4:1 water-methanol mixture and separation using a centrifuge.

Size Dependence and Color

Name: _______________ Date: _____________

Instructions:

You are given 3 vials of gold nanoparticles and a laser. Record the appearance of the solution in the table below and then pass the laser through the solution. Record the color you see.

Keywords to record appearance: Transparent, Intermediate or Opaque

Orange/Purple	Largest		
Red	Intermediate		
Brown	Smallest		

Results and Conclusions:

1. As size increases, what trend did you observe with the appearance of the solution?

2. As size increases, what trend did you observe when the laser passed through the solution?

Electrode Preparation

List of Material and reagents needed:

- Goggles
- Gloves
- Glass pipettes

Fluorine doped Tin Oxide (FTO) Electrode from Harford glass 1 inch x 1 inch. Contact: hartfordglass@live.com or TEL: 1-765-348-1282 for ordering the FTO electrode.

Solar energy glass

NSG TEC™

Performance data summary

Product	Thickness (mm)	Light Transmittance (%)	Solar Direct Transmittance (%)	Sheet Resistance (Ohms/sq)	Haze (%)
NSG TEC™ A7	2.2	82	70	7	5

An equivalent product for the FTO will be https://www.sigmaaldrich.com/catalog/product/aldrich/735140?lang=en&region=US

- Binder clips
- Multimeter
- UV-Vis spectrophotometer and LabQuest control unit
  https://www.vernier.com/products/sensors/spectrometers/visible-range/gdx-svispl/
  https://www.vernier.com/products/interfaces/labq2/
- Hot plate
- Bunsen burner
- TiO_2 paste https://shop.solaronix.com/titania-pastes/ti-nanoxide-r-sp.html
- Potassium iodide
- Milli-Q water

Assembly of electrode:

Done by instructor -

1. Sonicate the FTO electrode for 10 minutes in acetone/ethanol bath for two cycles
2. After drying, coat TiO_2 past using a glass rod to distribute an even layer
3. Bake the electrode on a hot plate till all the organic material burns away. The FTO electrode will turn from white → brown → white
4. Then place a layer of ~1 nm AuNP solution and dry on a hot plate.
5. On a second FTO electrode deposit a uniform layer of carbon soot to make the second electrode using a Bunsen burner

Done by students -

6. Then place the electrodes together, taking care to keep one edge exposed and join them with binder clips
7. Add a couple of drops of electrolyte material (1M Potassium iodide).
8. Connect the alligator clips to the exposed edges and in turn to a multimeter

Note: A similar commercial kit (Nanocrystalline solar cell) is available through the following websites: (1) http://ice.chem.wisc.edu/Catalog/SciKits.html (2) http://ice.chem.wisc.edu/KitComponents/SolarCell_SuppliesList031411.pdf

Please note that although the construction of the electrode system is similar, we have not tested our solutions with this commercial kit.

Measuring Voltage and Current

Name: _______________ Date: _____________

Instructions:

In this experiment you are provided with two solar cells – one with nanoparticle (NP) and another without NP. Compare the voltage and current outputs between the two electrodes.

Step 1: Assemble the electrode by adding two FTO electrodes with binder clips.

Step 2: Fill electrolyte in between the two electrodes.

Step 3: Measure the voltage and current using the multimeter provided.

Formula:

V = I * R

Where V = Voltage. Unit is Volts (V).

I = Current. Unit is Amperes (A).

R = Resistance. Unit is Ohms (Ω).

Current (I) = $\frac{V}{R}$

	V_1	V_2	V_3	Avg	R_1	R_2	R_3	Avg	
A (without NP)									
B (NP)									

Results and Conclusions:

1. Which sample generates more current and voltage?

2. Based on your observations, comment on the role of nanoparticles in building solar cells and generating electricity.

Case Study Report

Name: _______________ Date: _____________

Instructions:

In this report, write a letter to the Department of Energy, Washington Avenue, Annapolis, MD 20000, convincing them that the state should fund their proposal to install solar panels at your school.

Description:

Your description should include a claim that nanoparticles are more efficient components to make solar cells, which is one of the solutions to meet the growing energy demands at your school. Your report should include the following sections:

1. **The Claim** (Identify a claim relevant to your project)
2. **The Need** (Talk about the Green Energy initiative at your school)
3. **The Evidences** on what makes nanoparticles an efficient component in renewable energy applications. (Draw evidences from your experimental findings and from the model lesson you were engaged in. You are allowed to gather relevant information conducting research via digital sources, multimedia etc.)
4. **Concluding Remarks** (Include a concluding statement.)

Format:

Use Times New Roman 12 font, double spaced, maximum 3-4 page limit with 1 inch margins.

Rubric

	2	1	0
The Claim	The claim provided is clear, concise and in scientific terms. Clearly presents the main idea and supports it throughout the paper.	The claim provided is somewhat clear, concise and in scientific terms. Clearly presents the main idea supported throughout most of the paper.	The claim provided is vague and not in appropriate scientific terms. The idea is weak and not supported throughout the paper.
The Need	The need is well-presented and argued. Descriptions are detailed and well-developed.	The need is well-presented and argued, but not clearly articulated. Descriptions lack sufficient details.	The need is not clearly argued. Ideas lack sufficient details.
The Evidences	Sources are exceptionally well-integrated and they support claims argued in the paper very effectively. At least 2 or more facts as well as examples are provided in detail.	Sources provided are not clearly integrated to support claims argued in the paper. At least one fact or an example is provided.	Sources provided are not clearly integrated to support claims argued in the paper. Neither facts nor examples is provided.
Concluding Remarks	Includes a clear summary statement well-supported by scientific reasoning. Conclusion is logical and clearly indicates synthesis of ideas.	Includes a summary statement but poorly supported by scientific reasoning. Conclusion is somewhat logical and indicates synthesis of ideas to some degree.	Does not includes a summary statement. Conclusion does not provide logic and lacks synthesis of ideas.
Organization	Writing is coherent, paragraphs have smooth transitions between ideas.	Writing is somewhat coherent, paragraphs do not have smooth transitions between ideas.	Writing lacks coherence and do not have smooth transitions.