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Cover Page Footnote

We would like to acknowledge Amy Zeh, the Program Director of Service Learning at UCF, for her assistance in grading the critical reflections, as well as Melody Bowden, Executive Director of the Karen L. Smith Center for Faculty Teaching and Learning at UCF for her editing of the manuscript.

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Assessment of the Effect of Service-Learning in Nanoscience on Student's Depth of Learning and Critical Thinking Depth of learning and critical thinking skills in a new Nanoscale Science and Technology course which incorporates service-learning was investigated in a sample of 12 undergraduate students at the University of Central Florida. Students were given a Nanoscience pre- and post-test, as well as asked to write two drafts of a final critical reflection at the end of the course. The overall learning of students was assessed, and results clearly show improvement between both pre- and post-tests and the draft and final versions of the critical reflections. We associate this improvement at least in part with the service-learning experience.

Keywords: Nanoscience, Education, Service Learning, Critical Reflection

The University of Central Florida (UCF) and, in particular, the Colleges of Sciences, Engineering and Education have made a solid commitment to advancing, strengthening, and promoting Science, Technology, Engineering, and Mathematics (STEM) education. This is partly due to the expected demand for one million additional college STEM graduates in the next decade in the U.S. (President's Council of Advisors on Science and Technology (U.S.), 2012), a nation like many others facing a gradual decrease in interest in STEM fields, ironically at a time when technology is playing an increasingly important role in the lives of everyone. Perhaps, the most appealing aspect of STEM education and its relation to sophisticated technical positions in industry resides in training American undergraduates at the nanoscale.

Nanoscience and nanotechnology deal with the study and manipulation of systems at the nanoscale (with at least one dimension below a few hundred nanometers), which display distinct phenomena unique to their small size, with impact across multiple disciplines including physics, chemistry, biology, materials science and engineering, and with highly promising applications. Although nanoscale research certainly has and will continue to play a huge role in revolutionizing cutting-edge science and technology, there is currently a lack of qualified students attracted to fields relevant to nanotechnology. Many universities do not have the resources to properly expose students to nanofabrication processes, despite recommendations from both the President's Council of Advisors on Science and Technology and the NSF (Roco, 2001) to focus on education and training of a new generation of graduates with at least some familiarity with nanoscience and technology. For these reasons, UCF has approved a new degree in Nanoscale Science and Technology, which was offered for the first time in Fall 2015 and has been built around three new core "nano-courses" which can be taken in any order and were designed to cover the basics of nanoscience and nanotechnology, including societal impacts of emerging nanotechnologies. In the "nano-courses" discussed here, there exists a three-fold goal:

i. UCF students learn nanoscience concepts from disseminating independent research on advanced topics related to the course contents (*i.e.*, learning by teaching);
ii. Pre-college students be exposed to the most attractive aspects of STEM fields of study -those that relate to the nanoscale and can have a great impact in society-, with a high potential to convince them to choose this particular path in their academic development; and,
iii. Middle school teachers and students will benefit from permanent dissemination products developed through their interactive collaboration in the project.

The above goals, particularly the last two, may seem to imply some connection between the students enrolled in the courses and a pre-college, middle school audience; in fact, all three courses are designated as service-learning. For those unfamiliar with the term, the American Association of Community Colleges (AACC) describes service learning as "combining community service with classroom instruction, focusing on critical, reflective thinking as well as personal and civic responsibility" (AACC, n.d.); for a more in-depth discussion of service-learning courses and teaching methods, see (Heffernan, 2001). Each of the three courses requires those enrolled to teach a local middle school class about an aspect of the course they found interesting, combining more traditional teaching methods with a form of community service which would ideally assist in recruiting even more young minds into following a STEM-related career path. The students themselves gain a sense of personal and civic responsibility, first by being responsible for designing and implementing their own lecture to a classroom, and second by going out into the community and educating young members (in particular, prospective female STEM workers) about nanoscience and technology.

The first course, "Nanoscience II: Technology and Applications," was offered to a class of 12 students in the Fall semester of 2015, and consisted of 60% lecture and 40% service-learning (not optional). The lecture portion covered an overview of the basics of nanotechnology, and heavily emphasized student interaction. Homework assignments were given as mini-research topics, with groups or individuals learning about a topic on their own and presenting it in class to their peers. The service-learning portion consisted of groups of students choosing emerging technologies in nanoscience to research outside of class and present to a student audience at local middle schools which were suggested to the researchers by the Executive Director of Secondary and Middle Schools in their district. The idea behind this approach was that a majority of the students' learning would come from their own research, both at the individual level and through interactions with peers, as well as from exposure to the broader audience in middle schools through the service-learning activities. In addition to simply being a course requirement, the hope from a community service standpoint was that the service-learning presentations (each of which had at least one female presenting) would help to encourage middle school students, particularly female students who remain underrepresented in many of the hard sciences, to become more interested in pursuing careers in STEM; that the student presenters themselves would act as role models, particularly the female presenters. There has of course been a significant amount of research done on the positive impact of female role models in recruiting and retaining women in STEM (Craig, 1998; Butler & Christensen, 2003; Robst, Keil, & Russo, 1998; Etzkowitz, Kemelgor, Neuschatz, & Uzzi, 1994).

In fact, the middle school teachers communicated with the students to decide on what topics would be the best fit for each classroom, as the younger student audience ranged from 6th to 8th grade. This fostered a sense of collaboration between the students themselves and the wider community. As a complement to the nanoscience topics being presented, the students also shared their experiences at UCF and their future career plans. From an academic standpoint, the advantages of using service-learning as a pedagogy have been known for many years and are described in numerous studies (Giles Jr & Eyler, 1994; Markus, Howard, & King, 1993; Bringle & Hatcher, 2000). These advantages include but are not limited to an increase in the following: student engagement in class, problem-solving skills, critical thinking skills, and community engagement.

Regarding why these courses, in particular, were designed to incorporate service-learning, while UCF has a strong presence overall in service-learning education and an entire department dedicated to furthering the utilization and understanding of experiential learning methods, hardly any of the service-learning courses currently offered focus on a scientific topic. For example, in the Spring 2016 semester, out of the 14 service-learning designated courses that will be offered, two are nursing courses and eleven have to do with creative writing, teaching, or other humanities. The only service-learning course being offered this semester and having to do with STEM is the nanoscience course which is the continuation of the course discussed in this paper. Given how involved the university is in service-learning activities, the researchers felt it was necessary to bring nanoscience into the fold and begin offering nanoscience courses with a service-learning component to the undergraduate students. As this is only the second physics service-learning course the department has offered (the other one designed to train future physics teachers), a study into its effectiveness is certainly warranted to determine if this teaching method for this subject should be continued in the future.

Although significant research has been done on the effect of service-learning on non-STEM courses (Whitely, 2014; Molee, Henry, Sessa, & McKinney-Prupis, 2010; Warren, 2010; Ash & Clayton, 2009; Giles & Eyler, 2013; Moely & Illustre, 2014; Lockeman & Pelco, 2013), to date comparatively little has been dedicated to examine service-learning in science and technology focused courses in general, and nanoscience courses in particular. In the current study, the researchers use learning assessment results to explore students' depth of learning and critical thinking throughout a new nanotechnology course which significantly incorporates service-learning. To accomplish this goal, nanoscience pre- and post-tests (see Appendix A) were given to the students at the beginning and end of the semester to quantify overall depth of learning, while students completed a critical reflection at the end of the semester specifically geared towards the service-learning experience. Each student wrote a first draft, received feedback from the instructors, and turned in a final reflection. The drafts and final versions were then made anonymous by standardizing format and labeled with random numbers, and given to the Program Director of Service-Learning at UCF to score according to the Describe, Examine, and Articulate Learning (DEAL) model (Ash & Clayton, 2009). This model has been shown in numerous other research studies to be an effective way of assisting students in developing their critical thinking skills (Fisher & Mittelman, 2013; Bai, Larimer, & Riner, 2016) as well as in evaluating those skills (Ash & Clayton, 2009).

Method

Research Participants

Research participants were the 12 students enrolled in the course students enrolled in the course PHZ 3464 Nanoscience II: Technology and Applications at UCF in Fall 2015. They included one sophomore, one junior, and ten seniors. Their majors included physics (6), chemistry (2), biology (1), and engineering (2). Five of the twelve participants were female.

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The purpose of this research was explained to all participants in accordance with IRB protocol and all students enrolled in the course elected to participate.

Course Setup

The Nanoscience II: Technology and Applications course was designed to emphasize student learning outside the classroom. The main goal of the class was to improve students' ability to discuss and present on their own research topics in current nanoscience fields. Forty percent of the total grade came from the service-learning project (15% from in class presentations, 15% from the final reflection paper, and 10% from their presentations in the middle schools), while 60% came from more formal coursework (40% from exams and 20% from homework). Homework consisted entirely of students choosing a topic related to what had been discussed in class, researching it on their own or in groups, and presenting it to the class. These oral presentations were graded according to a rubric that was made available to the students at the beginning of the semester (contact the researchers for a description of this rubric). Lectures by the professor were augmented by presentations by students, opportunities to research for and discuss their service-learning projects, and occasional trips to experience microfabrication facilities in person (with hands-on activities included).

Figure 1
Students presenting in the middle school classrooms

Note: A) The group presenting on "Using Nanotechnology to filter/purify water" shows students a culture of bacteria under a microscope. B) The group presenting on "Wearable Nanotechnology" shows students the difference between a normal glove and a nanoparticle-coated water repellent glove. C) The group presenting on

"Using Nanotechnology to treat/cure diseases" demonstrates the ability of nanoparticles to 'stick' to certain cells via an interactive game.

The service-learning project consisted of groups of students contacting local middle school teachers, choosing a current exciting application of nanoscience, and researching it on their own to present to the middle school classes. The students went online to the journal *Nature* to select several articles concerning new and emerging nanotechnology applications, which they then submitted to the teaching assistant (TA). Students were grouped according to their interests and assigned a more general topic that included the applications they had researched. There were four groups of three students each, and they presented their topics to two different middle school classes (see Figure 1) – a total of eight different classes (~20 middle school students per class) at three different schools were involved. The students were instructed to emphasize relatability and audience interaction in their presentations and to minimize lecturing and use of PowerPoint slides. They were graded on an in-class progress report and the middle school presentations (contact the researchers for these rubrics), and the final reflection paper (see the DEAL model rubric in Appendix B). Additionally, each student presented a final poster project in class which was designed to be submitted to the annual university service-learning showcase in 2016.

The middle school teachers the participants worked with were very excited about this project. The response from the middle school students overall was quite positive, with teachers' comments including "Thanks so much for coming to my class today! I can tell they really enjoyed it! As, did I! It was really great!" (M. Francher, personal communication, November 2, 2015) and "They really loved it!" (K. Bennett, personal communication, November 3, 2015). Several teachers requested additional presentations from the students as well. They are eager to continue working with our courses in this manner and are currently collaborating with students enrolled in the second core course of the degree.

Assessment

Students were given a pre- and post-test on the first and last day of class, consisting of 27 multiple choice questions that examined their general knowledge of nanoscience topics (Appendix A). Although several previously designed nanoscience concept inventories were found (Dhananjay, et al., 2012) (Mitin, Liu, Bell, & Fulmer, 2009), they were intended for upper-level courses and heavily emphasized engineering processes. Thus a more general, introductory nanoscience concept inventory was developed by the professor and TA. This was done before the curriculum was designed, in order to avoid tailoring it to the curriculum specifically rather than nanoscience in general. As will be discussed later, marked improvement was seen over the course of the semester.

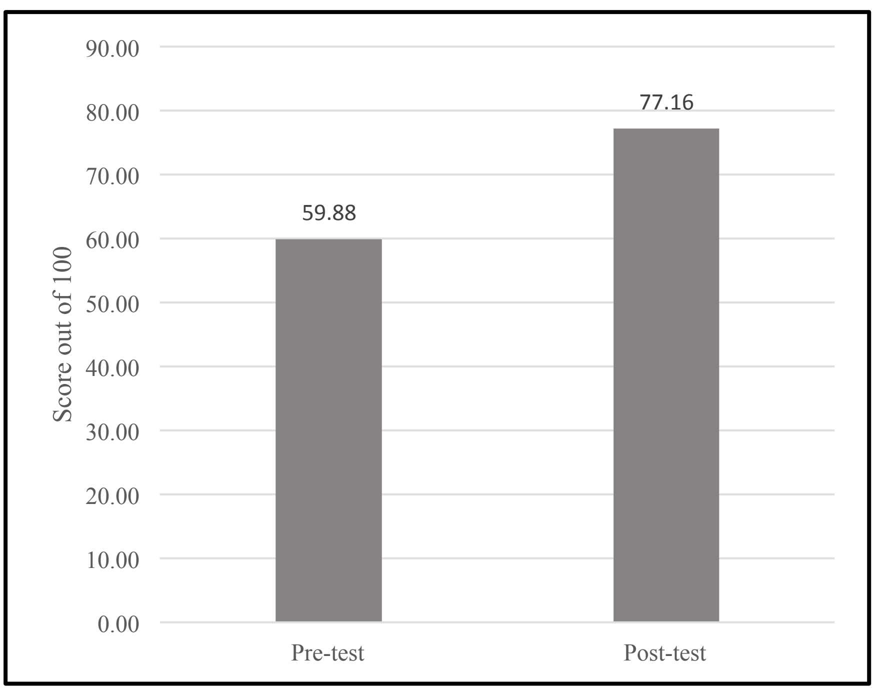
Towards the end of the semester, students were asked to write a two-page critical reflection paper concerning their service-learning project, how it affected them, and how they felt it affected the community. They were provided with a copy of the DEAL model rubric that was used to score the reflections (see Appendix B) before writing their first drafts. The drafts were read by their instructors, who gave feedback and suggestions. The students then submitted a final reflection paper on the last day of class to be anonymously scored alongside their drafts by the Program Director of Service-Learning at UCF, according to the same rubric that had been provided to the class. Drafts and final versions were made anonymous by standardizing all formatting and removing both the titles and the student's names. They were then assigned random numbers, with drafts mixed in with final versions, before giving them to a scorer who had no previous contact with the students. The idea behind this method of scoring was to quantify improvement in critical thinking skills while maximizing objectivity from the scorer. Overall results did show improvement.

Finally, after the conclusion of the class, students were asked to complete a post-survey (Appendix C) asking them to rate statements from Strongly Agree to Strongly Disagree concerning the impact of their service-learning experience as well as how much they felt the service-learning portion contributed to their overall learning in the class. This survey was modeled after a post-survey used by the UCF Arboretum (UCF Arboretum, n.d.) to assess the impact that service-learning courses involving work in the Arboretum have had on their educational experiences. Students were guaranteed that the professor was not going to identify the respondents, as everything was handled by the TA without informing the professor on the individuals submitting. Nine of the twelve students participated in the survey.

Results

Results show clear improvement in both subject knowledge and critical thinking skills. The post-test showed an average percent gain of 28.86%, with a p-value (using a paired, two-tailed T-test) of 0.000321, t-value of -5.1435, and Cohen's d-value of -1.3807. The initial mean score (out of 100) was 59.88 with standard deviation of 16.246, while the final mean score was 77.16 with standard deviation of 7.03 (see Figure 2). The critical reflection papers showed an average percent gain of 11.54%, with a p-value (again via a paired, two-tailed T-test) of 0.00326, t-value of -3.7407, and Cohen's d-value of -1.496. Both the concept inventory and critical reflection papers had n = 11 degrees of freedom.

Figure 2
Average nanoscience concept inventory total scores (out of 100) for the pre- and post-test.



Questions for the post-test were split into the following categories: Undergraduate Quantum Mechanics, Semiconductor Physics, Micro-device Fabrication, Nanoscience, and Nanotechnology/ Applications. The percent gains for each category are shown (see Figure 3A).

As can be seen in Figure 3, Nanoscience and Nanotechnology/Applications show the greatest average percent gain over the semester as well as having fairly low pre-test scores. As could be expected for a nanoscience course focused on technological applications, those two categories showed the most improvement.

Students performed well on both the drafts and final versions of the critical reflection papers, with the mean score for the drafts (out of 100) being 88.64 with standard deviation of 9.59 and that of the final submissions 98.87 with standard deviation of 1.19. Students were scored on the following eleven categories:

i. Integration: Drew connections between the experience and the learning
ii. Relevance: Kept discussion focused on the learning
iii. Accuracy: Statements were accurate and well-supported
iv. Clarity: Provided examples, illustrated points, and defined terms
v. Precision: Gave specific descriptions or data
vi. Writing: No typographical, spelling, or grammatical errors
vii. Depth: Avoided oversimplifying and addressed questions that arise from statements that were made
viii. Breadth: Considered alternate points of view or alternate interpretations
ix. Logic: Conclusions consistently followed the line of reasoning
x. Significance: Substantially addressed the most significant issue(s) raised by the experience
xi. Fairness: Represented others' perspectives without bias.

Percent gains as well as average scores for both drafts and final submissions are shown in Figure 4. With the exception of Writing and Breadth, each category had a final score of 100%. The main area students struggled with was the breadth of their reflections; that is (Appendix B), "Giving meaningful consideration to alternative points of view and making good use of them in shaping the learning."

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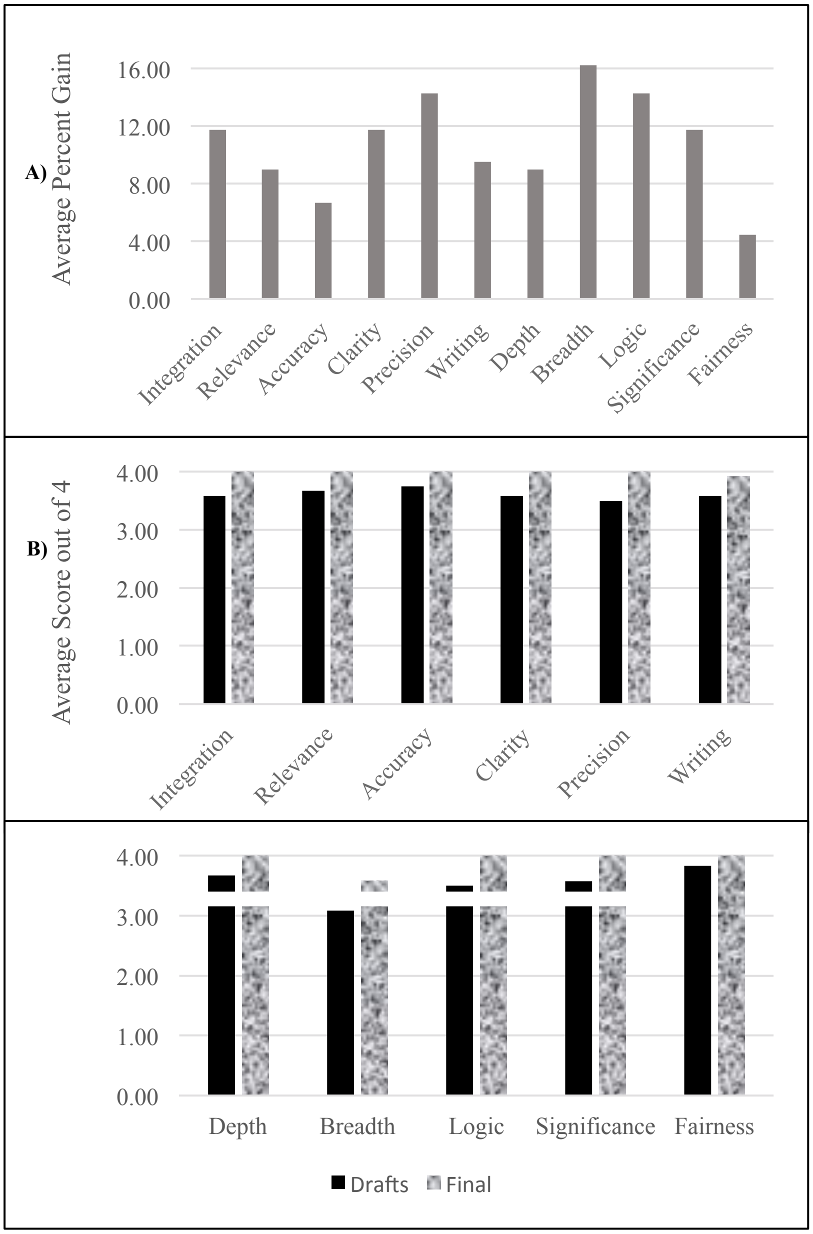
Figure 4
Critical Reflection Scores



Note: A) Average percent gain for each category. B) Average total scores (out of 4) in each category for both drafts and final submissions

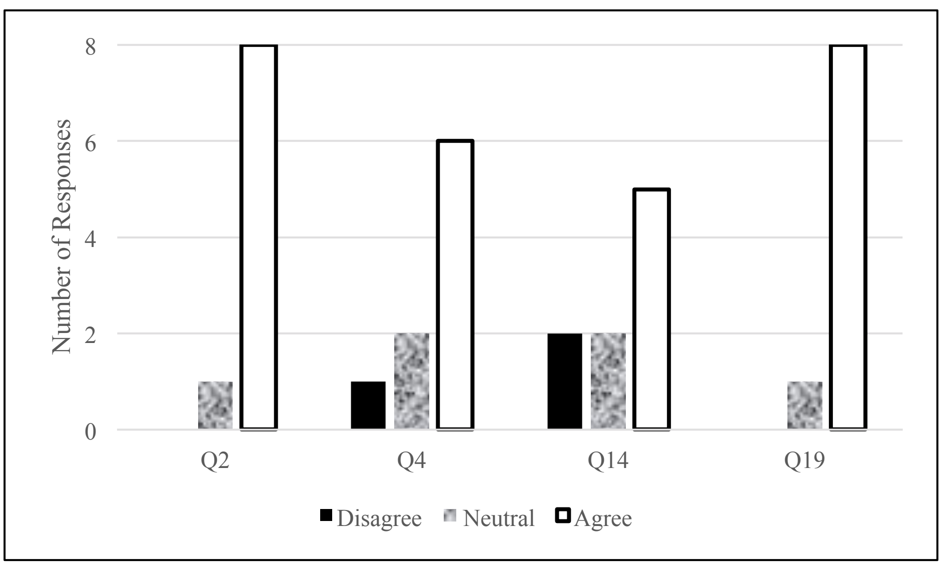
Finally, the service-learning post-survey (Appendix C) showed very positive responses towards the service-learning experience as a whole, as well as how it impacted their more conventional learning in the classroom. A desire to continue involvement with the community was demonstrated in general, and participants reported that the service-learning experience helped them gain a clearer idea of career goals as well as becoming more marketable in their chosen profession. As to academic engagement, students reported an increased interest in the course material pertinent to their individual presentation projects, which encouraged them to voluntarily study those topics in more detail than they would have in a normal, non-service-learning course.

The following statements have been isolated as most relevant to identifying the service-learning experience's impact on academic learning in the classroom:

> *Q2: The community work I did increased my ability to understand and apply the academic course material.*
>
> *Q4: The reflection activity added to my learning experience by helping me to consider course concepts more deeply.*
>
> *Q14: Outside of class time and service hours, I frequently thought about the issues raised in class.*
>
> *Q19: I have a better understanding of nanoscience and technology because of my service experience.*

Figure 5

Student responses to the post-survey questions



Note: Responses have been grouped into three categories: Agree (include both Agree and Strongly Agree), Neutral (Neither Agree nor Disagree), and Disagree (includes both Disagree and Strongly Disagree). The total number of responses for each question is 9.

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Discussion

Assessment of student depth of learning and critical thinking skills show a definite improvement over the course of the semester. While this improvement could be due simply to the lecture and formal coursework, student responses indicate that it is at least in part due to the service-learning project and classroom preparation for it. Comments from the students as well as the post-survey point to significant impact of service-learning on both traditional learning and future careers. The researchers believe that a large reason why such learning gains are observed is increased student engagement in the course, stemming from the service-learning projects. This is supported by student responses to survey questions and comments to instructors concerning the effect service-learning had on their interest in the course.

As an interesting note, the statements isolated in the last paragraph of the results are similar to some questions asked of students in the service-learning focus groups in (Prentice & Robinson, 2010, p. 7), namely "Did participating in service learning help you to learn or understand the course material better?" and "Did service learning help you to learn specific skills or knowledge that you might not learn in college classes that did not offer service learning?" From positive student responses to both focus group interviews and more standard surveys detailed in their report, Prentice & Robinson drew the conclusion that service-learning appeared to be a definitive positive contributing factor to students' academic learning. However, for their surveys (although not their focus groups) they were able to gather data from similar courses both with and without service-learning as a comparison, which was unfortunately not possible in the study discussed here.

Limitations of this study include the fact that the number of students who participated is quite small, and without a non-service-learning comparison group. Additionally, there was only one grader for the critical reflection paper; while this does eliminate any question of interrater reliability, it requires accepting a single evaluation of students' critical thinking skills. The current study thus relies somewhat on student response and opinion, and although critical reflection improvement was quantitatively observed it would be beneficial in the future to have multiple graders to ensure grading is as fair, impartial, and accurate as possible. Nonetheless, the researchers believe this to be an encouraging starting point for evaluating the effect that service-learning has on students' overall learning, knowledge, and critical thinking skills in nanoscience-based courses. Although just recently implemented, the new UCF "Nanoscience and Nanotechnology" degree continues beyond the first course (studied in this paper), with the other two core courses being offered in consecutive semesters. Increasing interest has been detected from students enrolled in many science majors as more people become aware of the new program, and enrollment is expected to grow steadily in the near future. The current plan is to continue studying the effect of service-learning in subsequent courses, as well as examining the students' opinions on the use of service-learning in these courses.

Looking ahead even further, the researchers plan to follow up with participating students to analyze their future academic and career paths, which will be compared to data obtained from students of the same majors not enrolled in the nanoscience service-learning degree. The goal will be to determine the impact of this degree on the academic and professional decisions undertaken by students as a result of their exposure to the service-learning activities in the constituent core courses. If student response continues to be positive, incorporating service-learning may prove to constitute a way of drawing more undergraduates towards STEM fields and nanoscience, in particular, addressing the need for qualified graduates in the workforce.

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About the Authors

• Rebecca Cebulka is a graduate student at the University of Central Florida. Her research focuses on studying the strong-coupling between microwave photons in superconducting resonators and the spins of single-molecule magnets, among other studies of the quantum dynamics in molecular nanomagnets. She is also involved in the development of service-learning nanoscience minor at UCF, and participates in physics outreach activities among local schools.

• **Enrique Del Barco** is a professor at the University of Central Florida. While his research group focuses on nanomagnetism, spintronics, and electronic transport at the nanoscale, he is also very involved in physics research education, physics outreach among local primary and secondary schools, and the development of a servicelearning nanoscience minor at UCF.

Appendix A: Nanoscience and Technology Concept Inventory

BIRTH MONTH/DAY: (MM/DD) (/)
GENDER: F M
Nanoscale science and technology concept inventory
(Choose only one answer per question)

1. *The Wave-Particle duality refers to the phenomenon in which atomic particles while in motion*
    a. *appear to float around*
    b. *create waves in collisions*
    c. *behave sometimes as waves and sometimes as particles*
    d. *cause ripple effects*

2. *Quantization of energy refers to the observation that*
    a. *energy is radiated or absorbed in discrete "quanta" or "energy packets"*
    b. *small quantum amounts of energy must be used for best results*
    c. *restricted use of energy leads to quantization of energy*
    d. *a fair distribution of energy requires its division into equal parts or "quanta"*

3. *The Uncertainty Principle states that*
    a. *nothing in nature is certain*
    b. *the outcome of any experiment at the nanoscale cannot be predicted*
    c. *the simultaneous measurement of position and momentum is inherently inaccurate*
    d. *ambiguity leads to uncertainty*

4. *The Schrodinger equation*
    a. *specifies when the quantum state of a physical system does not change with time*
    b. *is used to measure dimensions below 100 nanometers*
    c. *enables studying the inner side of atomic particles*
    d. *is to quantum mechanics what Newton's second law of motion is to classical mechanics*
    e.
5. *According to the Pauli Exclusion Principle*
    a. *particles with the highest energy are excluded from any stable system*
    b. *no two identical particles may occupy the same quantum state simultaneously*
    c. *particles with low energy and those with high energy interact in an exclusive manner*
    d. *antisymmetry in wave functions of particles is the result of chemical bonds*

6. *The term quantum tunneling refers to the phenomenon when a particle*
    a. *reaches the other side of a potential energy barrier that it classically could not be surmount*
    b. *displays the wave-particle duality of matter*
    c. *both a and b*
    d. *neither a nor b*

7. *Energy bands*
    a. *are ranges of allowed energies for electrons moving in periodic potentials, such as in a crystal lattice*
    b. *are the energies of a beam of particles when moving together*
    c. *are associated with sound (i.e., mechanical vibrations) in crystals*
    d. *are related to light moving inside nanoscopic materials*

8. *Fermi energy*
    a. *is the energy of the highest occupied quantum state in a system of electrons at absolute zero*
    b. *relates to the energy of systems that conduct electricity in a non-Ohmic way*
    c. *characterizes the quantum energy of atomic vibrations in solids*
    d. *is the energy of a free electron at rest in vacuum*

9. *What is a single-electron transistor?*
    a. *a transistor made of semiconductor material*
    b. *a device which works with thermal electrons*
    c. *a device operating with tunneling of electrons one at a time*
    d. *a transistor that cannot be replicated*

10. *Why is graphene, a two-dimensional atomically flat sheet of carbon atoms, so relevant in nanoelectronics?*
    a. *Because of its excellent mechanical properties*
    b. *Because of its transparency to visible light*
    c. *Because of its high electrical mobility and absence of a band-gap*
    d. *Because electrons move quantum-mechanically*

11. *The photolithography process is analogous to which of the following processes?*
    a. *writing on stone*
    b. *photographic process*
    c. *scanning process*
    d. *curing process*

12. *The Moore's law is due to*
    a. *Price of silicon reduction over time*
    b. *Larger silicon wafers*
    c. *Transistor size scaling*
    d. *Modern circuit architectures*

13. *The process responsible for creating N-type and P-type regions in a semiconductor is known as*
    a. *mixing*
    b. *annealing*
    c. *deposition*
    d. *implantation*

14. Which process can be used to transfer material onto a wafer?
- *a. Physical and chemical deposition*
- *b. Electrochemical etching*
- *c. Nanowire transferring*
- *d. None of the above*

15. What characteristic optical response can you obtain in a nanosized metallic particle?
- *a. transparency*
- *b. plasmonic resonance*
- *c. mirror reflection*
- *d. spherical refraction*

16. Colloidal suspensions of nanosized particles display different colors due to
- *a. their intrinsic color*
- *b. the laser effect in nanotechnology*
- *c. the Heisenberg Uncertainty Principle*
- *d. the size of the particles in suspension*

17. A photonic crystal is
- *a. A crystal able to reflect all photons at all frequencies*
- *b. A periodic structure that interacts resonantly with a particular wavelength*
- *c. A crystal that behaves as a metal for photons*
- *d. A crystal made of nanoscale crystallites oriented all in the same direction*

18. Spintronics is
- *a. Electronics employing the spin degree of freedom of electrons*
- *b. Electronics employing the charge degree of freedom of electrons*
- *c. Electronics with magnetic devices*
- *d. Electronics of circular devices (e.g., nanocoils) in which electrons spin*

19. What is the typical size of a magnetic domain inside a ferromagnetic material?
- *a. 1 Å*
- *b. 1 nm*
- *c. 100 nm*
- *d. 1 μm*

20. A carbon nanotube displays amazing mechanical properties, such as
- *a. It is 1/6 the weight of steel and 100 times its tensile strength*
- *b. It is 6 times the weight of steel*
- *c. It is 100 times harder than steel*
- *d. It conducts electricity an order of magnitude better than copper*

21. What is a NEMS?
- *a. a nano-electromagnetic system*
- *b. a nano-electromechanical system*
- *c. a non-electromagnetic system*

   d. *a native electromechanical system*

22. *Nanostructures are relevant in catalysis because*
   a. *their small size allows fabricating devices with small size*
   b. *they maximize the active surface area to promote chemical reactions*
   c. *nanoparticles move faster than macroscopic materials*
   d. *they would produce innocuous byproducts*

23. *In what way can nanoparticles can be used as biosensors?*
   a. *Increasing contact between proteins*
   b. *Facilitating transport of medicines through cell membranes*
   c. *Copying DNA strands of a virus or a bacterium*
   d. *Tagging antibodies to determine what infection may be present*

24. *Optical tweezers*
   a. *use light to break large molecules in small parts*
   b. *use light to manipulate nanoscale biological systems*
   c. *are small tweezers (nano-scale) which can only be seen under an optical microscope*
   d. *tweezers used to trap optical photons*

25. *Nanofluidics deals with*
   a. *the flow of liquids through nanoscale channels*
   b. *liquids made of nano-bio-systems (such as proteins)*
   c. *slippery surfaces in nanoscale biological tissues*
   d. *the flow of blood and other bio-systems in veins and arteries*

26. *Nanoencapsulation of drugs by nano-shells allows*
   a. *drugs to be delivered faster into the blood stream*
   b. *curing illnesses related to open viruses*
   c. *drugs to be delivered to the brain*
   d. *producing small-sized pills*

27. *Nanoparticles could be used*
   a. *to fight cancer by directly slowing tumor growth*
   b. *as contrast agents in MRI*
   c. *to prevent sunburn by bonding to skin cells*
   d. *to promote stronger muscles*

Appendix B: DEAL Model Rubric Used to Score Critical Reflections

DEAL Model Critical Thinking Rubric

[Modified source: Paul, R & Elder, L. 2001. The Miniature Guide to Critical Thinking. The Foundation for Critical Thinking. Santa Rosa, CA. www.criticalthinking.org]

	(1)	(2)	(3)	(4)
CT Set A				
Integration	Provides no clear connection between the experience and the learning	Provides minimal and/or unclear connection between the experience and the learning	Provides adequate and reasonably clear connection between the experience and the learning	Provides thorough and very clear connection(s) between the experience and the learning
Relevance	Misclassifies the learning and/or inappropriately shifts from one category of learning goal to another; fails to keep the discussion specific to the learning	Discusses learning that is relevant to the category of learning goal, but much of the discussion is not related to the learning	Discusses learning that is relevant to the category of learning goal and keeps the discussion reasonably well focused on the learning	Discusses learning that is relevant to the category of learning goal and keeps the discussion well-focused on the learning
Accuracy	Consistently makes inaccurate statements and/or fails to provide supporting evidence for claims	Makes several inaccurate statements and/or supports few statements with evidence	Usually but not always makes statements that are accurate and well-supported with evidence	Consistently makes statements that are accurate and well-supported with evidence
Clarity	Consistently fails to provide examples, to illustrate points, to define terms, and/or to express ideas in other ways	Only occasionally provides examples, illustrates points, defines terms, and/or expresses ideas in other ways	Usually but not always provides examples, illustrates points, defines terms, and/or expresses ideas in other ways	Consistently provides examples, illustrates points, defines terms, and/or expresses ideas in other ways
Precision	Consistently fails to provide specific information, descriptions, or data	Only occasionally provides specific information, descriptions, or data	Usually but not always provides specific information, descriptions, or data	Consistently provides specific information, descriptions, or data
Writing	Consistently makes typographical, spelling, and/or grammatical errors	Makes several typographical, spelling, and/or grammatical errors	Makes few typographical, spelling, and/or grammatical errors	Makes very few or no typographical, spelling, and/or grammatical errors
CT Set B				
Depth	Fails to address salient questions that arise from statements being made; consistently over-simplifies when making connections; fails to consider any of the complexities of the issue	Addresses few of the salient questions that arise from statements being made; often over-simplifies when making connections; considers little of the complexity of the issue	Addresses some but not all of the salient questions that arise from statements being made; rarely over-simplifies when making connections; considers some but not all of the full complexity of the issue	Thoroughly addresses salient questions that arise from statements being made; avoids over-simplifying when making connections; considers the full complexity of the issue
Breadth	Ignores or superficially considers alternative points of view and/or interpretations	Gives minimal consideration to alternative points of view and/or interpretations and makes very limited use of them in shaping the learning being articulated	Gives some consideration to alternative points of view and/or interpretations and makes some use of them in shaping the learning being articulated	Gives meaningful consideration to alternative points of view and/or interpretations and makes very good use of them in shaping the learning being articulated
Logic	Draws conclusions and/or sets goals that don't follow at all from the line of reasoning presented	Draws conclusions and/or sets goals that only occasionally follow reasonably well from the line of reasoning presented	Draws conclusions and/or sets goals that usually follow well from the line of reasoning presented	Draws conclusions and/or sets goals that consistently follow very well from the line of reasoning presented
Significance	Draws conclusions and/or sets goals that don't address the most significant issue(s) raised by the experience	Draws conclusions and/or sets goals that only minimally address the significant issue(s) raised by the experience	Draws conclusions and/or sets goals that usually address fairly significant issue(s) raised by the experience	Draws important conclusions and/or sets meaningful goals that substantially address the most significant issue(s) raised by the experience
Fairness	Consistently represents others' perspectives in a biased or distorted way	Occasionally represents others' perspectives in a biased or distorted way	Often but not always represents others' perspectives with integrity	Consistently represents others' perspectives with integrity (without bias or distortion)

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Appendix C: Service Learning Post-Survey
Nanotechnology Service Learning Post Survey

A) For the following questions please rate your response from 1 - 5; 1-Strongly Agree, 2-Agree, 3-Neither Agree nor Disagree, 4-Disagree, 5-Strongly Disagree.

1) The community service aspect of this course helped me to see how the subject matter can be used in everyday life.
   1 2 3 4 5
2) The community work I did increased my ability to understand and apply the academic course material.
   1 2 3 4 5
3) The academic course material (e.g. readings and lectures) enhanced the service that I performed.
   1 2 3 4 5
4) The reflection activity added to my learning experience by helping me to consider course concepts more deeply.
   1 2 3 4 5
5) The reflection activity helped me to see the connections between my service experience and the course material.
   1 2 3 4 5
6) I feel I would have learned more from this course if more time was spent in the classroom instead of doing work with the community.
   1 2 3 4 5
7) The service aspect of the course showed me how I can become more involved with my community.
   1 2 3 4 5
8) I feel that my service-learning work in this course benefitted the community.
   1 2 3 4 5
9) I will probably continue to volunteer or participate with the community after this course.
   1 2 3 4 5
10) The community service involved in this course helped me to become more aware of the needs of my community.
   1 2 3 4 5
11) This learning engagement helped me to gain a clearer idea of my educational goals (for example, my major or minor).
   1 2 3 4 5
12) This learning engagement helped me to gain a clearer idea of my professional goals (for example, my career).
   1 2 3 4 5
13) The service I performed and the skills I developed will make me more marketable in my chosen profession when I graduate.
   1 2 3 4 5

14) Outside of class time and service hours, I frequently thought about the issues raised in class.
1 2 3 4 5

15) The service component caused me to think about my attitudes, values and perspectives.
1 2 3 4 5

16) During my service learning, I engaged in positive interactions with people from different social, economic, and ethnic backgrounds than mine.
1 2 3 4 5

17) This class caused me to feel more concern about social problems in the community.
1 2 3 4 5

18) I have a better understanding of complex scientific issues because of my service experience.
1 2 3 4 5

19) I have a better understanding of nanoscience and technology because of my service experience.
1 2 3 4 5

20) I have a better understanding of STEM education issues because of my service experience.
1 2 3 4 5

B) For the following statements please rate your response from 1 - 4; 1-Significantly, 2-Moderately, 3-Slightly, 4-Not at all.

1) My service-learning experience in the UCF nanotechnology course impacted my ability to engage in/commit to service in the community
1 2 3 4

2) My service-learning experience in the UCF nanotechnology course impacted my ability to be socially responsible
1 2 3 4

3) My service-learning experience in the UCF nanotechnology course impacted my ability to use knowledge/skills in a work situation
1 2 3 4

4) My service-learning experience in the UCF nanotechnology course impacted my ability to apply course content to the real world
1 2 3 4

5) My service-learning experience in the UCF nanotechnology course impacted my ability to pursue my career goals
1 2 3 4

6) My service-learning experience in the UCF nanotechnology course impacted my ability to take initiative
1 2 3 4

7) My service-learning experience in the UCF nanotechnology course impacted my ability to volunteer for new roles
1 2 3 4

C) Please list any additional comments regarding your service-learning experience in the UCF nanotechnology course: