IMPACT OF INCORPORATING OUTREACH INTO AN UNDERGRADUATE LEVEL INTRODUCTION TO NANOTECHNOLOGY COURSE: RESULTS AND INSIGHTS FROM A SMALL SCALE STUDY

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Keywords: nanotechnology, undergraduate, outreach.

Abstract
A small-scale study was undertaken to evaluate the impact of incorporating K-12 outreach into an undergraduate introduction to nanotechnology course at an engineering college. A 3-credit special topics course was conducted where the traditional lecture and exam format was complemented by lab sessions in which undergraduate students researched a topic of their choice in nanotechnology, and subsequently designed, built and taught engineering design challenges suited for late elementary and middle school students in a family science setting. The undergraduate students first learned to explore new topics while performing a literature review on their nanotechnology topic. They then distilled core concepts and societal and technological implications of their topics as they designed their pre-college engineering design challenges. Finally, students learned to communicate these ideas as they formulated detailed lesson plans and taught underrepresented school students and their families.

The course was taught twice and the implementation assessed by an independent evaluator. In the first implementation, improved undergraduate student interest in research/teaching, and self-perceptions of teaching and leadership skills were observed. The second implementation examined the perceived relative benefits of the various conventional and unconventional learning techniques employed in the course. Overall satisfaction with the course was high with practice assignments and classroom lectures being identified as most beneficial for topics outside their own chosen topics, and teaching their own lectures and literature reviews as most beneficial for their chosen topics.

Introduction

Nanotechnology can be defined as the control and study of matter in the size range of ~1-100 nm, with the objective of creating new materials, devices and systems that exhibit fundamentally new properties and functions by virtue of their nanoscale structure. Since the launch of the US National Nanotechnology Initiative in 2000, this area, which sits at the confluence of physics, chemistry, biology and engineering, has been the focus of considerable scientific and societal efforts [1]. The resultant body of knowledge has been accompanied by the gradual introduction of programs, minors and courses in nanotechnology [2]. The highly interdisciplinary and research based nature of the subject matter has meant that integration of nanotechnology into the engineering curriculum typically takes places at the advanced undergraduate level. Nevertheless, the inclusion of research advances into the undergraduate curriculum is widely accepted as resulting in undergraduates being more persistent, gaining intellectually and being more likely to choose a research related field as a career [3]. Research related activities with the strongest association to deep learning gains are reviewing literature and interpreting findings [4]. A low cost means of achieving such benefits at the introductory level is to integrate primary literature sources into the course [5]. Separately, external evaluations of developments in the informal science education space have correlated integration of outreach into general engineering courses with undergraduate student self-reported gains in communication skills including communicating complex science ideas to non-scientific audiences, understanding of teaching practices, and increased knowledge of the community [6-10]. Here we report on the results of a small scale study of the impact of introducing outreach elements and primary literature sources into an undergraduate level introduction to nanotechnology course.

Course Design and Rationale

A 3-credit course with lecture as well as "lab" components was created. The lectures were designed to deliver a more conventional experience, in which the students learned the fundamentals associated with eight different topics in nanotechnology through a case study for each topic. The topics were chosen to exemplify how changing the nanostructure of materials affects properties. In addition, two topics were chosen to represent characterization and nanofabrication/processing. The final lecture topics and associated case studies were: electronic properties (graphene and 2D materials), opto-eletronic properties (quantum dots and quantum wells), optical properties (photonic crystals and metamaterials), magnetism (superparamagnetism), mechanical properties (polymer nanocomposites and nanocrystalline metals), nanofabrication (block copolymers, DNA origami and photolithography) and characterization (super-resolution optical microscopy). Mid-term and final exams and homework problems were used to assess student learning on these topics.

In the labs, groups of 2-3 students were asked to create nanotechnology themed, household materials based engineering design challenges suited for late elementary and middle school students in a family science setting. The lab component of the course had three sub-components, which we designated as *learn*, *design* and *teach*, respectively. In the *learn* component of the lab, students learned about a research topic of their choice by first performing individual literatures surveys and submitting reports. They then pooled their literature surveys and wrote a combined report. The intent was for the students to learn to conduct a literature review of a new topical area. This was assessed on the students' ability to correctly identify at least one review paper, two seminal works, and two papers describing recent advances in the field.

The second desired learning outcome was for students to come to a broad understanding of the scientific and engineering principles behind a nanotechnology on the basis of a collection of journal articles. This was assessed through the clarity of the report as well as a multi-level concept map and associated in-class presentation that students made on their topic.

The third desired learning outcome for the learn component was for students to be able to come to an appreciation of the high level societal implications of scientific and technological advances through a collection of journal articles. This was assessed through the quality of the sub-topics in the concept map presentation. Additionally, students were asked to identify and expand on two concepts that could serve as the basis of a design prompt for their family science engineering design challenge.

In the second component of the labs, the students were asked to create a design challenge based on household materials which satisfied certain criteria. This component was included with the expectation that students would gain a deeper understanding of their particular research topic by having to distill a scientific or technological concept to the extent that it became accessible to elementary and middle school students and their families. The design challenges were assessed on the basis of a rubric that measured if they had an explicit goal and multiple solutions, and were explanatory, exciting, testable and original.

The third component of the labs involved having the students create lesson plans and teach their design challenges to late elementary school and middle school students and their parents. The school students were chosen to be from high needs schools with high percentages of economically disadvantaged students, as defined by free and reduced price lunch eligibility, as well as underrepresented minorities in STEM. The family science courses thus connected the engineering students with underserved children and their parents/guardians with the aim of supporting the children to practice science and develop creativity, persistence, and critical thinking skills. This component of the course was informed by evidence based knowledge about student learning from various informal science education programs involving college students [6 -10]. It was expected that similar gains in communication skills, appreciation for teaching, and community engagement would result amongst the undergraduate students. Six of the engineering design challenges along with inspirational videos of scientists involved with the research are hosted on a widely accessible informal science education website.

Methods

The impact on undergraduates, was independently assessed by an external evaluator, subsequent to verification of the instrument by an Institutional Review Board. In the first implementation of the course, a total of 17 undergraduate students completed the course. Sixty-five percent of students in the class were male; 29% female and one citing gender as fluid (6%). The majority of students (64%) were sophomores (29%) and juniors (35%); about a quarter of students were seniors (24%); one was a freshman (6%); and one individual did not provide a response (6%). Almost all students who registered for the class were majoring in some field of engineering with a little over half majoring in Materials Engineering (n=9). One student was a science/social science double major. 82% of the students satisfied the pre-requisite requirement of having taken a freshman level introduction to materials engineering course. In the second implementation the emphasis of the evaluation was shifted to compare the conventional and unconventional components of the course and the participants were restricted to Materials Engineering majors. An additional element was added to the second implementation, where students were asked to present a 40-minute lecture to their fellow students at the level of the other lectures in the course. Students were also required to provide three learning objectives for their lecture. A total of seven undergraduate students completed a pre-survey at the start of the course. Of these undergraduates, over half were male (57%) and 43% identified female. The class included three seniors, two juniors, and two sophomores.

In the first implementation of the course, surveys assessed students' skills in a number of areas (teaching, leadership, communication, teamwork) and interest in pursuing a research-related and/or teaching career. Surveys also examined undergraduates' experiences in developing their design approach/challenges, the impact of teaching the family science course, as well as overall course satisfaction. A pre-survey was administered on the first-day of the course and post surveys at the end of the semester. A total of 17 students completed both a pre and post survey (100% response rate). In addition to the instruments developed by the external evaluator, formal university course evaluations were administered to students (N=12; 71% response rate). In the second implementation, six undergraduates completed the surveys. Two aspects are worth noting here. First, the numbers in the second implementation are low. Second, it was found that the trends in course satisfaction were maintained across the two implementations. Thus, despite the low numbers, we discuss some insights from the data.

Results

In the first implementation, on university course evaluations, all students who completed an evaluation (n=12, 71% response rate) indicated they were satisfied with the course overall, of whom three quarters of students strongly agreed that the course was excellent. On matched pre and post surveys, students were asked more specifically about their satisfaction with the lecture (L) and non-lecture (NL) components of the LDT-Nano course. Overall, students were satisfied with both components; however, they rated the lecture components of the course more highly. On a 5-point scale the average lecture component was rated 4.32, while the learning from exposure to other students' research topics in the form of concept map presentation and design challenges was rated at 3.76. Satisfaction with both components of the course was further supported by student comments highlighting the structure and delivery of the course. For example one student commented "For the debut of this course, I was very pleased with the combination of literature research, lecture exposure to current scientific endeavors and the teaching aspect of the course. It challenged you to become so adept with the material that you would be responsible for its clear and correct interpretation by another student."

Students on pre- and post- surveys were asked to indicate how interested they were in pursuing a career in research and/or teaching. From the start to end of the program, there was a slight increase in overall interest, with one additional student expressing that they were very interested by the end of the course/program.

On pre- and year-end surveys, undergraduates were asked to rate how prepared they were to perform 13 teaching-related tasks on a 6-point scale, from 1=very unprepared to 6=very prepared. Notably, there was a significant improvement on the overall average teaching skills score for undergraduate students from pre ($M=4.7$; $SD=0.8$) to post ($M=5.4$; $SD=0.5$) conditions; $t(16) = -3.7$, $p<.01$. Undergraduates, on average, felt more prepared on all 13 indicators of teaching. Significant improvements in preparedness were seen for interacting/working with students (5.2 to 5.6) and family members (4.6 to 5.4), as well as collaborating with faculty advisors on the curriculum (4.8 to 5.6). Undergraduates' self-perceptions of preparedness also significantly improved in the areas of writing instructional objectives (4.5 to 5.5), planning engineering design challenge lessons (4.5 to 5.4), and teaching the subject matter content (4.7 to 5.6). From pre to post, undergraduates felt significantly more prepared to ensure equitable family participation (4.1 to 4.9) and the success of all students (4.6 to 5.3).

On pre- and post- surveys, undergraduates were asked about their leadership skills on 17 items which were on a 6-point scale, from 1=never to 6=all the time. Impressively, there was a significant improvement on the overall average leadership skills score for undergraduate students from pre ($M=4.8$; $SD=0.6$) to post ($M=5.1$; $SD=0.5$) conditions; $t(16) = -3.1$, $p<.01$. Additionally, a significant improvement was found for undergraduates' average ratings for the following items: showing the initiative needed to get the desired result (4.8 to 5.2), spending the time and effort necessary to build an effective team (4.8 to 5.2), and getting almost everyone to participate when leading meetings (4.4 to 4.7). Interestingly, the improvement on the overall communication skills score was not statistically significant (4.5 to 4.7), while no significant improvements were found on the 10 pre-post items related to teamwork, and the average rating remained the same at 4.8 on a 6-point scale from 1=never to 6=all the time. Finally, the majority of undergraduates (88%) reported being satisfied overall with the Family Science program, with over half indicating they were very satisfied.

The general trend of satisfaction with the course was maintained in the second implementation. On post- surveys, 100% of undergraduates were satisfied overall (67% indicated they were very satisfied and 33% were satisfied). Given the consistent trend, we report the results comparing the learning techniques implemented in the course, while reiterating the caveat of the lower student numbers. First, undergraduates were asked how much they benefited from certain learning techniques utilized during the course excluding their team's Nanotechnology Research Topic and Engineering Design Challenge. Such techniques included classroom lecture by the professor, lectures by other students, engineering design challenge and presentation of other topics, practice assignments, concept map presentation and studying for the exam. On post surveys, undergraduates were instructed to rank these techniques from 1 (least beneficial) to 6 (most beneficial). Table 1 illustrates undergraduate students' rankings with 1 denoting the highest ranking and a 6 representing the lowest ranking, along with the average score associated with each technique. Overall, students found the practice assignments (5.0), classroom lecture (4.8) and other engineering design challenges and presentation of topics (3.6) to be the most beneficial aspects of the course.

Table 1. Undergraduate Rankings & Average Scores for Course Learning Techniques

Learning Technique	Average Score	Ranking (highest to lowest)
Practice Assignments	5.0	1
Classroom Lecture by Professor	4.8	2
Engineering Design Challenge & Presentation of Other Topics	3.6	3
Studying for the Exam	3.2	4
Lectures by Other Students	2.4	5
Concept Map Presentation	2.0	6

Additionally, undergraduates were asked to rate the learning techniques associated with their team's Nanotechnology Research Topic and Engineering Design Challenge. Table 2 illustrates the ranking and average scores (1=least beneficial; 7=most beneficial) for the seven learning techniques associated with teams' research topic and design challenge. Overall, undergraduates found teaching their nanotopic lecture (6.2) and conducting the literature review (6.0) to be the most beneficial aspects of the experience pertaining to their own research topic and design challenge.

Table 2. Undergraduate Rankings and Average Scores for Research Topic/Design Challenge Learning Techniques

Learning Technique	Average Score	Ranking (highest to lowest)
Teaching your Nanotopic Lecture	6.2	1
Conducting a Literature Review	6.0	2
Creating a Design Challenge and Design Prompt	4.2	3
Teaching Family Science Events	4.0	4
Working with Your Teammates to Assimilate Literature Research into One Body of Work	3.4	5
Creating a Prototype and Refining the Design Challenge	2.4	6
Lesson Plan Development	1.8	7

To mitigate the possibility that the data in Tables 1 and 2 suggests that students seek an introduction to nanotechnology course where they focus only on the nanotechnology itself and not teaching others we note the following. When students were asked which learning technique they learned more nanotechnology material from, conventional (classroom lectures, studying for exams, example problems etc.) or unconventional (literary research, concept mapping, design challenges, family science, teaching a lecture etc.), two-thirds chose unconventional. When asked what was the most beneficial part of participating in the LDT Nano course, students specifically mentioned the engineering design challenge portions and family science events as well. Two example comments are "Teaching the in depth lecture at the end of the course, and additionally the engineering design focused lecture in the family science events. They were both very much out of my comfort zone, but I ended up having a lot of fun teaching students," and "Working on the challenge, having to develop a design challenge that could be tapered to different age ranges and that successfully explained a topic."

Finally, 100% of undergraduate students who completed a post- survey reported being satisfied overall with their experiences in the Family Science Events (67% were very satisfied and 33% were satisfied). As an example of the comments accompanying this question one student responded, "It was nice to jump into a teaching environment and try and spark some interests in STEM. I've spent three years learning such complex things that it was really fun to try and make a way to teach those complex things while making it interesting to younger kids."

Summary

We have reported on the results of a small scale study of the impact of introducing outreach elements and primary literature sources into a 3-credit hour undergraduate level introduction to nanotechnology course. In the first implementation, improved undergraduate student interest in research/teaching, and self-perceptions of teaching and leadership skills were observed. The second implementation provided insights into the perceived relative benefits of the various conventional and unconventional learning techniques employed in the course. Overall satisfaction with the course remained high with practice assignments and classroom lectures being identified as most beneficial for topics outside their own chosen topics, and teaching their own lectures and literature reviews as most beneficial for their chosen topics.

Acknowledgements
This material is based upon work supported by the National Science Foundation under Grant No. 1446038.

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