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Nanotechnology Fellows Program: Integrating Interdisciplinary Education, Professional Development, and Outreach

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Nanotechnology Fellows Program: Integrating Interdisciplinary Education, Professional Development, and Outreach

Abstract

An undergraduate Nanotechnology Fellows Program was established to addresses key problems in implementing nanotechnology education: (1) science and engineering curricula are already full; (2) practical, hands-on experiences require extensive training on complex, expensive equipment; and (3) necessary fundamental concepts and knowledge span multiple disciplines and are rarely taught at the undergraduate level. This work reports on the program evolution over the course of three years as well as the short- and long-term impacts on students' academic and professional careers. The evaluation results from the first year indicated the most profound impact came from integrating the interdisciplinary education, professional development, and outreach components to develop students' career and leadership skills. The nanotechnology education outcomes were secondary to the career and leadership development even though nanotechnology education and training was the primary program goal. Program modifications were made in the second and third years to capitalize on these initial results. The summative survey results for all three cohorts demonstrate the impact of these changes. The results point to the use of this integrated program approach as a tool for improving engineering education.

Introduction

In 2015, a Nanotechnology Fellows Program was established at The George Washington University (GWU) to prepare undergraduates for careers in emerging technologies. The program addresses key problems in implementing nanotechnology education: (1) science and engineering curricula are already full; (2) practical, hands-on experiences require extensive training on complex, expensive equipment; and (3) necessary fundamental concepts and knowledge span multiple disciplines and are rarely taught at the undergraduate level. Previous reports detailed the structure and composition of the program elements and participants as well as preliminary evaluation results [1], [2]. The program consists of interdisciplinary education and research components, hands-on training, professional development, and community outreach. The instructional team includes participants from the mechanical engineering, electrical engineering, engineering management, and chemistry departments as well as the university's Nanofabrication and Imaging Center. Over three years, twenty-six students have been selected for the Nanotechnology Fellows Program, and their majors span seven disciplines. Table 1 provides a summary of the program participation by gender and undergraduate major.

This paper reports on the program's evolution over the course of three years as well as the positive impacts on students' academic and professional careers. Formative and summative evaluation tools were developed by program evaluators in the Office of Academic Planning and Assessment and psychology department; the tools include student feedback analysis, focus groups, and surveys. The evaluation results from the first year indicated students valued all the program's components, but the most profound impact came from integrating the interdisciplinary education, professional development, and outreach components to develop students' professional skills. The nanotechnology education outcomes were secondary to the career development even though nanotechnology education and training was the primary program goal. Program modifications were made in the second and third years to capitalize on these initial results. Workshops and seminars were adapted and added to specifically highlight the link between the program components and their impact on students' career and leadership skills. The summative survey for all three cohorts demonstrates the lasting impact of these changes. The results point to the use of this integrated, interdisciplinary program approach as a tool for improving engineering education, particularly with respect to science, technology, engineering, mathematics (STEM) career pursuits.

Table 1. Summary of program participants by cohort, undergraduate major, and gender. F and M designate female and male, respectively. The major is based on the student's major at the time of his/her participation in the program; it does not account for changes in major either as an undergraduate or during further graduate studies.

Undergraduate Major	**Cohort 1**		**Cohort 2**		**Cohort 3**		**Totals by Discipline/Gender**
	F	**M**	**F**	**M**	**F**	**M**	
Electrical/Computer Engineering	2	2	1		1	3	9 (35%)
Biomedical Engineering			1	4	2		7 (27%)
Mechanical/Aerospace Engineering	2	2		1	1		6 (23%)
Engineering Management/Systems Engineering			1				1 (4%)
Civil/Environmental Engineering				1			1 (4%)
Computer Science*				1			1 (4%)
Physics					1		1 (4%)
Total Female	4		3		5		12 (42%)
Total Male		4		7		3	14 (58%)
Total	8		10		8		26 (100%)

* The student indicated computer science as a primary major but had a double major in physics.

From a multidisciplinary perspective, students' benefit from the program did not depend on his/her major: students of all disciplines benefitted both academically and professionally from the nanotechnology program. In this particular program executed at GWU, the program seemed to have less positive impact on students majoring in mechanical/aerospace engineering compared to students in electrical/computer and biomedical engineering. The program's combination of advanced technical topics and training along with professional skills development seemed critical to the overall benefit of the program.

Methods

Previous reports described the program structure and evaluation results in the program's first year [1]. Briefly, the eight-week long program consisted of four modules: (1) soft lithography and microfluidics, (2) fabrication (photolithography and electron beam lithography, deposition, and etch), (3) characterization (microscopy and electrical probing), and (4) finance and commercialization. Mornings were spent doing lessons on content area knowledge and explaining techniques, and afternoons had hands-on training and laboratory activities. One day per week and non-training times were devoted to a research project which spanned the full eight weeks. Professional development workshops and outreach activities were interspersed in the schedule throughout the program duration. The program concluded with students completing written (report and poster) presentations as well as a research talk.

While the program's goal was nanotechnology education, the faculty leading the program noticed the impacts of the program seemed greatest for aspects remotely (or not at all) related to nanotechnology. In response to what it observed anecdotally, the faculty team identified the need for an evaluation which would assess the broader academic and professional impacts of the program, beyond only the nanotechnology education impacts. A relevant survey was developed. The survey had three sections as follows:

I. About Your Experience in the Nanotechnology Fellows Program
II. Possible Impacts of the Nanotechnology Fellows Program
   a. Nanotechnology
   b. Career
   c. STEM
   d. Technical Competence
   e. Professional Skills
   f. Academic and Professional Maturity
III. About You

Section I asked students to rate the positive effect or benefit of each program element (e.g., lectures, hands-on training, professional development workshops). The rating options were "no," "low," "medium," or "high" benefit/impact with a fifth option of "NA or don't recall." Section II was designed to assess the different types of positive impacts a training program like the Nanotechnology Fellows Program might have on its students, and these possible impacts were organized by the topics indicated above in II a-f. The rating options were "not at all," "minimally," "moderately," and "extensively." The final section was designed to obtain details about the student's characteristics (e.g., undergraduate major, professional activities, future career/academic plans, and, optionally, sex and race/ethnicity).

The design of the survey focused on positive impacts of the program. The goal of this focus was multifold. First and foremost, a high response rate was critical because the sample size was low: the total number of program participants was twenty-six at the time the survey was administered. Low survey response rates could lead to missing significant outcomes. Shorter surveys result in higher response rates, so the survey length was a critical consideration. When the survey designers considered the length of the survey with assessments of both positive and negative impacts, it was decided the survey would be too long to achieve a high response rate. Additionally, the intention is to use the results to design future programs, so the evaluation team is interested in which program elements had strong positive impact and what type of impact those elements had.

The survey was administered in December 2017. The survey was sent to all twenty-six students who completed the fellowship. As a qualitative study, the survey's targeted sampling focused on the Nanotechnology Fellows Program participants with the goal of understanding the program's impact on them. In this way, the study goal does not aim to generalize the results to a broader population (e.g., all undergraduates or other institutions) [3]. It should be noted some of the students were no longer at GWU. (One transferred to another university, and nine had graduated before the survey was administered.) The survey was sent to the most up-to-date email address in the program records, but this might not have been accurate for students no longer at the university.

It is important to note this survey does not measure students' skills. For instance, a student might perceive he/she benefitted from a resume writing workshop. While the student's perception is captured, his/her actual skill (e.g., the quality of his/her resume) was not assessed and cannot be interpreted from these results.

Results & Discussion

There were twenty-three respondents to the survey which equates to an 88% response rate. The respondent breakdown by discipline is presented in Table 2.

Table 2. Summary of survey respondents broken down by discipline.

Undergraduate Major	Total # of Fellows (# and % of total)	Total Respondents (# and % of total)
Electrical/Computer Engineering	9 (35%)	9 (39%)
Biomedical Engineering	7 (27%)	5 (22%)
Mechanical/Aerospace Engineering	6 (23%)	4 (17%)
Engineering Management/Systems Engineering	1 (4%)	1 (4%)
Civil/Environmental Engineering	1 (4%)	1 (4%)
Computer Science	1 (4%)	1 (4%)
Physics/Biophysics	1 (4%)	1 (4%)
Did not identify	0	1 (4%)
Total	26	23

The overall program perception was in part measured by the question, "How likely is it you would recommend the Nanotechnology Fellows Program to a friend or colleague?" Table 3 shows the results categorized by major. The benefit of the program seems strongest for students majoring in electrical/computer and biomedical engineering, and the lowest benefit is for students in mechanical/aerospace engineering. The result is surprising given the program director – the faculty member with whom participants spend an overwhelming amount of the program time – is a member of the mechanical and aerospace engineering department. There are too many factors which could have contributed to this result to make any conclusions, and there may be no correlation to undergraduate major. Nonetheless, future work could explore the impact of nanotechnology education on mechanical/aerospace engineering students, particularly with respect to developing program designs to more strongly impact these students.

A key theme of the program was the concept of professional identity. Rather than viewing themselves as students and knowledge receivers, program faculty repeatedly reiterated how students were becoming professionals and knowledge creators. Table 4 shows the impact of this messaging on students by their responses to the prompt, "My participation in the

Nanotechnology Fellows Program increased my confidence in myself as a professional, not only as a student." Interestingly, the division in responses by major was more distinct, again with mechanical/aerospace engineering students indicating lower impact.

Table 3. Summary of responses to the prompt "How likely is it you would recommend the Nanotechnology Fellows Program to a friend or colleague?" broken down by discipline.

Undergraduate Major	Extremely likely 10	9	8	7	6	5	Not at all likely 1
Electrical/Computer Engineering	5	2	1			1	
Biomedical Engineering	5						
Mechanical/Aerospace Engineering	1	2	1	1			
Engineering Management/Systems Engineering		1					
Civil/Environmental Engineering	1						
Computer Science	1						
Physics	1						

Table 4. Summary of responses to the prompt, "My participation in the Nanotechnology Fellows Program increased my confidence in myself as a professional, not only as a student" broken down by discipline.

Undergraduate Major	Extensively	Moderately	Minimally	Not at all
Electrical/Computer Engineering	8	1		
Biomedical Engineering	5			
Mechanical/Aerospace Engineering		4		
Engineering Management/Systems Engineering	1			
Civil/Environmental Engineering	1			
Computer Science		1		
Physics	1			

The first section of the survey identified which specific aspects of the program were most beneficial to students. Table 5 below summarizes the components of the summer program which had the most positive impact on students. Fellows presented research – from lab activities to a two month long project – multiple times throughout the program, and this aspect of the program clearly had the highest impact. A large majority (83%) indicated the program extensively improved their presentation skills. Early in the program, students participated in a workshop on how to give an effective presentation. While this program component was beneficial (with 83% responding it was high impact), the act of presenting their research had higher impact on the students (with 91% indicating it was high impact). It is unclear whether the two components are correlated. In other words, would the "presenting your research" component have less benefit if the "How to Give a Presentation" workshop were absent?

All of the respondents indicated the "hands-on training on nanotechnology equipment" had high or medium benefit/impact, supporting one of the main motivations for establishing the program.

The result is somewhat unsurprising since students who applied to the program did so because they sought this unique opportunity for hands-on training. However, this result is particularly intriguing since relatively few students indicated they planned to "get a job related to nanotechnology" (17% of respondents) and/or "attend graduate school related to nanotechnology" (35% of respondents) after graduation. It is not evident which aspects of the hands-on training were beneficial or why they were beneficial although a wide body of educational research on experiential learning motivated the inclusion of this program element and could be used to explore this finding [4].

Advising and mentoring were also key benefits of the program. Each research project was mentored by a graduate student, and the graduate students provided background information, training, and project guidance. The graduate student mentoring was a formal component of the program design, and its impact was clear with 92% of respondents indicating this component had high or medium positive benefit/impact. On the other hand, mentoring by the program faculty (i.e., the principal investigators) was not a formal component of the program design. Although the program faculty communicated a willingness to continue mentoring fellows after the program was complete, there was no requirement that students partake in this mentoring. Moreover, after the program this mentorship was not initiated by the program faculty. Nonetheless, fellows sought this mentoring which provided high or medium positive benefit/impact to 82% of respondents. The survey did not collect information regarding why respondents selected particular ratings, so it is not possible to conclude why certain program components were more highly rated than others. However, students in the program applied specifically to get hands-on training and lectures/tutorials on nanotechnology equipment and topics, so the significant impact of these program components (higher than the other program components) is understandable.

Table 5. Percent of survey respondents indicating certain program components had high or medium benefit/impact.

Program Component	**High Benefit/Impact**	**Medium Benefit/Impact**
Presenting your research	91%	9%
Hands-on training on nanotechnology equipment	87%	13%
Lectures/Tutorials	83%	13%
"How to Give a Presentation" workshop	83%	13%
Interdisciplinary research project	70%	22%
Graduate student advising on research project	70%	22%
Informal mentoring by program faculty after completing the program	65%	17%

The second section of the survey aimed to assess the impacts of the Nanotechnology Fellows Program. Perhaps unsurprisingly, the nanotechnology-specific outcomes were high impact with 100% of respondents indicating the program "extensively" increased their knowledge of nanotechnology and 91% indicating the program "extensively" increased their nanotechnology equipment expertise and research skills.

The impacts on career interests were particularly interesting. A majority of respondents indicated the program extensively helped them start thinking about their future career plans (78%) and broadened their exposure to a variety of fields and careers (74%). The program moderately or extensively increased interest in pursuing a career in *nanotechnology* for 78% of respondents while it moderately or extensively increased interest in pursuing a career outside nanotechnology *but within STEM* for 83% of respondents (a difference of one respondent). However, the increased nanotechnology career interest did not necessarily play out in post-graduation plans. When asked what they plan to do after graduation, 13% responded "get a job related to nanotechnology," and 26% responded attend graduate school related to nanotechnology. (Students were allowed to select all applicable options, so these two categories were not mutually exclusive.) On the other hand, 29% and 26% responded "get a job not related to nanotechnology but within STEM" and "attend graduate school not related to nanotechnology but within STEM," respectively. It is not clear why the interest in nanotechnology does not result in post-graduation nanotechnology-related pursuits. Nonetheless, the program may have aided in retention since 91% indicated the program moderately or extensively influenced them to stay in a STEM career. In fact, when asked to describe additional benefits or positive impacts from the program after completing it, several students indicated positive benefits related to obtaining jobs. The responses below exemplify the impact:

> I have been asked in every single interview about my experience in this program. The breadth of material and skills covered make it a very good talking point for any field.
>
> The program made it much easier for me to find internships. Companies and research labs were very impressed by the experience I had gained in the program, helping me get internships at the U.S. Naval Research Laboratory, Raytheon, and NASA. The program also helped my communication skills greatly and gave me the confidence to do well in interviews and network better.

The responses indicate both the academic and professional development components of the program combined to have positive impacts on the students. In other words, a program with one element or the other (academic topics or professional skills addressed separately without intimate integration) might have less positive impact than the model used here.

Conclusion

Nanotechnology is an inherently interdisciplinary field. The undergraduate Nanotechnology Fellows Program assessed here was designed to somewhat ignore students' undergraduate majors and focus on improving their advanced technical and professional skills, irrespective of discipline. The evaluation results indicate students significantly benefited from the presentation components of the program (i.e., presenting their research projects), and the program positively impacted their career focus and ability to get advanced technical jobs.

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