Works in Progress: Impact of First-Year Micro-/Nano-Technology Research Project Course on Future Research and Graduate/Professional School Involvement

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Introduction

The first-year engineering program at The Ohio State University provides honors students with the option to undertake a research and development design project with a focus on lab-on-a-chip (LOC) and nanotechnology applications. This project is an alternative to a robot design-build course which has a focus on mechanical engineering and computer programming[1]. This paper will ask the evidence-based practice question: "*Does a research and development design project course influence a student's decision to become involved in future research projects and pursue higher education in the form of graduate and professional school?*" We hypothesize that a significantly greater percentage of the research project course alumni will be involved in various research roles and activities and pursue higher education as compared to the alumni from the robot design course. To measure future research involvement, alumni who have completed the first-year engineering honors program within the past four years have been surveyed. As LOCs and nanotechnology have many applications in medicine, many students that enroll in this course are biomedical engineering and chemical and biomolecular engineering majors.

This rigorous research and development project course provides students with an understanding of the research process and develops the necessary skill sets and interest that encourage involvement in research as an undergraduate and promotes consideration of higher education. This may be in part explained by the students' initial interest in research as demonstrated by enrolling in a research project course (which will be controlled for), as well as by the skill sets developed while taking the research project course.

Students participate in research for a variety of reasons, including the desire to become a scientist or to clarify, confirm, or refine their educational and career goals[2]. At The Ohio State University, participation in research is approximately 22.4% for undergraduate students[3]. According to the 2012 US Census, 18.6% of students are continuing education in graduate schools[4]. STEM graduate programs in the US have enrollments between 40%-70%+ international students[5]. This research course may train a generation of domestic students to attend graduate school and reduce many universities' dependence on international applicants.

This study was conducted under IRB exempt protocol # 2013E0570 in accordance with the Office of Responsible Research Practices.

Study Population

Participants in this study have all completed the introductory honors engineering, Fundamentals of Engineering for Honors (FEH), track at The Ohio State University. This track is open to first-year students that have demonstrated academic achievement in high school and have been given "honors" status by the university. The first semester (Autumn) introduces students to problem-solving, working in groups, and two programming languages: C++ and MATLAB. The second semester (Spring) introduces students to drawing, 3D modeling, and a 10-week design project. There are two options for the design project: a robot design-build course and an alternative nanotechnology (nano) research course. The study has included students who have completed the honors engineering sequence in the past four years. Approximately 1500 students have completed the sequence over the past four years, and the distribution by course and year can be viewed in Table 1 below.

Table 1: Distribution of student participants by course and year

Year	Robot	Nano	Total
2010	307	39	346
2011	277	47	324
2012	293	61	354
2013	342	103	445
Total	1219	250	1469

Course Structures

This class prepares students for research by developing necessary skills in several key areas. Students are exposed to the full methodology of research design, including the development, manufacturing, and testing of an LOC device. The course culminates with a judged poster forum and technical slideshow presentation of the students' research and results. In contrast, the students who take the robot design-build course are instructed in various aspects of mechanical design, which includes drive trains, motor performance, statics, and strength of materials. The objective is to create an autonomous robot which students program to complete specific tasks on a competition course. Both course options have students participate in groups of three or four.

Both options have recently switched to an inverted classroom pedagogical model in which the content remains the same, but each instructional day is divided into two parts: preparation and application[6-8]. The preparation is directed at the lower Bloom's Taxonomy levels, and the application targets the upper Bloom's Taxonomy levels[9]. Table 2 below shows the components and timing of a typical inverted class day schedule. Before class, students are first introduced to the material and are evaluated. In class, this material is reviewed through a brief lecture and reinforced through guided activities and assignments. After class, assignments are completed and students prepare for the next class.

Table 2: Typical Inverted Class Day Schedule

Before Class	In Class	After Class
• Preparation activity: Reading, video, tutorial, or problem(s) • Evaluation: online quiz or turned in solution	• Short lecture • Activities • Application assignments or lab	• Finish application assignments, open lab • Prepare for next class

The course consists of five major components, including experimental microfluidics, nanotechnology research, group presentations of nanotechnology topics, a poster presentation, and an oral presentation, which comprise approximately 50%, 20%, 10%, 10%, and 10% of the course project grade, respectively. The poster and oral presentations are part of a final competition that judges students based on research quality and presentation skills.

A. Experimental Microfluidics

In this component, teams design, build, and implement a Lab-on-a-chip device to test a hypothesis regarding cell attachment to surfaces examining variables similar to the experiments conducted by Mercier-Bonin et al[10]. The semester long design/build/research project offers teams working knowledge of biomedical devices based on nanotechnology, microfluidics, and microscale engineering. Along with the hands-on activities at the microscale, various reading modules and lab tours introduce the techniques necessary to develop technology at the micro- and nanoscale. The challenge of this project is to produce a design for the experimental device, manufacture that design in a biocompatible material, and study the effect of surface topology on cell attachment. Additionally, computational fluid dynamics (CFD) software is then introduced both as a tool for educational purposes (allowing the students to visualize the flow properties described in other materials) and as a method to analyze their devices. They later use the software to perform sensitivity analyses of microfluidic channel dimensions and to characterize the flow in their own custom-designed microfluidic chip, which allows them to interpret the results of their experiments on cell adhesion. The students are given project objectives, general device requirements, specific on-chip requirements, and validation protocols to guide experimental design throughout the semester.

B. Lab-on-a-Chip Extensions and Nanotechnology Research

In tandem with the development of a microfluidic chip for research on cell attachment, the teams are also tasked with designing a device capable of detecting a disease from a blood sample. This project must be able to capture and detect a specific analyte of interest from a collected blood sample. This analyte must be found in the blood and indicative of a specific disease state (inflammation, heart disease, cancer, HIV, etc.).

Well-defined micro- and nanoscale channels can provide better understanding of fundamental fluid transport at the dimensions relevant to bacteria, viruses, proteins, DNA, and other nanoscale analytes. The ability to understand and manipulate materials at this size scale is valuable for chemical and biological applications. Another challenge lies in the specific detection of these analytes, and a number of strategies have been developed harnessing various physical phenomena (e.g. fluorescence, magnetic properties, electric fields, enzymatic reactions, etc.) to provide means of analyte detection. The students must choose an appropriate medical application for their chip such as the devices discussed above, and design a device that incorporates imposed constraints to make a useful, clinically relevant tool.

Additionally, students are given ideal characteristics, required features, required constraints, and specific tasks to guide their design. Students also conduct a technical literature review towards the beginning of the semester to develop familiarity with literature search tools and strategies.

C. Cool Nano Topic of the Day (CNTOTD) Group Presentations

The Cool Nano Topic of the Day (CNTOTD) is a semi-casual presentation given by each team two times throughout the course. This prepares students for formal presentations of technical information. The goal is a brief (approximately 10 minutes), informative presentation about any area of nanotechnology that the team finds interesting, would like to learn more about, and share with the class. Typically the presentations are done using PowerPoint. Students are encouraged to choose topics that emphasize material related to the course. The goal is to make the topic as specific as possible and explain it with as much depth as possible. Narrowly defined topics with a deep understanding of the details are preferred over broad topics with limited depth.

D. Microfluidics Poster Presentation

Students design a poster for a formal presentation on the microfluidic experiments described above. These posters are then printed and supplied for a final competition. The poster serves as a visual aid for a brief presentation given by all group members to judges. Students are given access to guidelines, a template, an outline, and samples as a starting point for creating their posters. Students are typically judged three times. Judges come primarily from academia, including faculty, graduate students, and undergraduate alumni of the course; students are guaranteed one judge from each category. As seen in Figure 1 below, the environment is similar to a poster session at a technical conference.

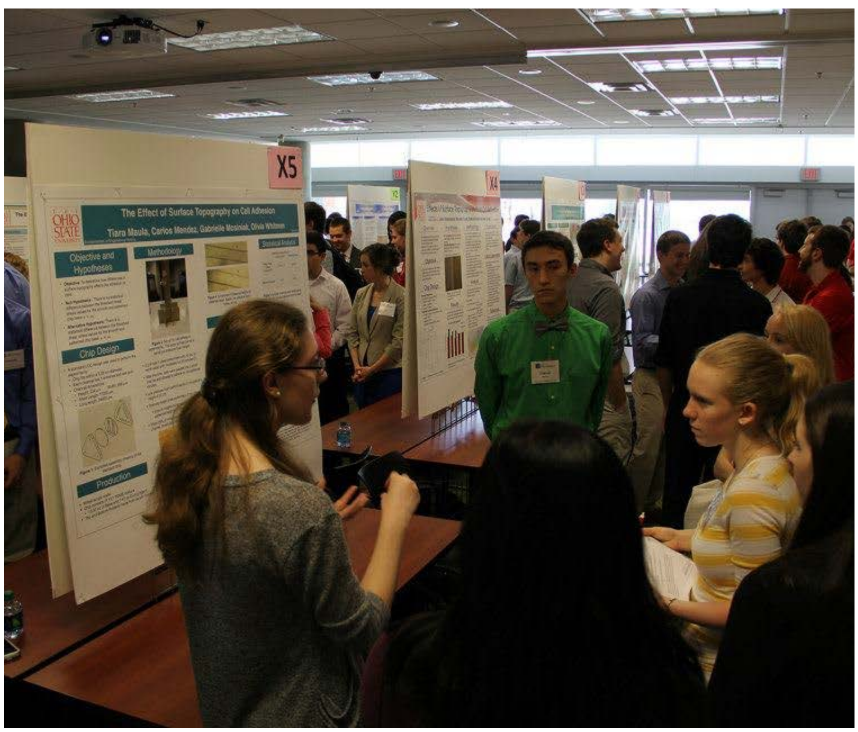

Figure 1: Microfluidics poster competition

E. Nanotechnology Oral Presentation

The nanotechnology oral presentation allows the groups to explain and justify their proposed nanotechnology design. This is a formal technical presentation that is judged by faculty and staff. Students are encouraged to present their design in a way that would convince investors to fund their project. Students are required to include the following sections: background/medical application, preliminary concepts, design process, final design explanation, and future research. Additionally, students create and present a complete working drawing set of their nanotechnology device in SolidWorks. Presentations conclude with a question and answer period. A strict time constraint is enforced, and presentations are expected to be professional and well-rehearsed.

Approach

It is believed that alumni of the nanotechnology course will have increased involvement in research and intentions of attending graduate/professional school. To measure future research involvement, alumni who have completed the first-year engineering honors program within the past four years were surveyed to quantify their involvement in various research roles and activities, including undergraduate research, presentations at technical forums and conferences, research and development internships, as well as planned participation in graduate or professional school. The survey consists of a variety of multiple choice, check boxes, and optional short answers. The survey was combined with another study and was sent out via a survey link email. The survey was created and results were stored in Qualtrics Survey Software (qualtrics.com). Aggregate information was used to protect the privacy of participants in the study.

In addition to consent, major, course and year completed, the questions below in Table 3 were asked regarding the hypothesis.

Table 3: Survey questions and answer choices

Questions	**Answer Choices**
1. PRIOR to taking ENGR 193/1282, did you plan to conduct any type of research during your undergraduate career? This may include research lab positions, research-oriented design teams, undergraduate thesis, or research-oriented co-ops or internships.	Yes
	No
2. SINCE taking ENGR 193/1282, have you conducted any type of research outside of coursework? This may include research lab positions, research-oriented design teams, undergraduate thesis, or research-oriented co-ops or internships.	Yes
	No
3. [If 'No' to question 2] Do you plan to conduct research in the future? Again, this may include research lab positions, research-oriented design teams, undergraduate thesis, or research-oriented co-ops or internships.	Yes
	No
4. In which kinds of research have you participated?	I have no research experience
	Undergraduate research
	Research-oriented design team
	Research-oriented internship/co-op
	Undergraduate thesis
	Technical forum/conference presentation
	Other (please specify)
5. [If any answer besides 'I have no experience with research' to question 4] Please indicate your level of agreement with the following statement, "My experience in my ENGR 193/1282 project course helped me decide to get involved with research."	Strongly Disagree
	Disagree
	Neutral
	Agree
	Strongly Agree
6. PRIOR to taking ENGR 193/1282, did you plan to attend graduate or professional school?	Yes
	No
7. SINCE taking ENGR 193/1282, do you plan to attend graduate or professional school?	Yes
	No

Results

The survey was sent via email through Qualtrics with a link to the survey to all alumni of the honors engineering program from 2010 through 2013. A summary of the numbers from each year is shown in Table 4. Based on Tables 1 and 4, the overall response rate was 24.23%, while individual response rates from Robot and Nano were 24.12% and 24.80%, respectively.

Table 4: Year and course option cross table

		Which option did you take?		
		Robot	Nano	Total
When did you take the course?	Spring 2013	86	25	111
	Spring 2012	78	17	95
	Spring 2011	60	12	72
	Spring 2010	70	8	78
	Total	294	62	356

The course options were cross-tabulated to create Tables 5-8 below. Percentages were used for comparative purposes, but totals are indicated above. Statistical values were calculated using a Chi-squared test in Minitab, and can be viewed in Table 9 below.

Table 5: Questions 1-3

	PRIOR to taking ENGR 193/1282, did you plan to conduct any type of research during your undergraduate career?		SINCE taking ENGR 193/1282, have you conducted any type of research outside of coursework?		Do you plan to conduct research in the future?	
Course Option	Yes	No	Yes	No	Yes	No
Robot	32.08%	67.92%	36.86%	63.14%	33.15%	66.85%
Nano	66.13%	33.87%	50.82%	49.18%	70.00%	30.00%
Overall	38.03%	61.97%	39.27%	60.73%	38.32%	61.68%

Table 6: Question 4

	In which kinds of research have you participated?						
Course Option	I have no exp. with research	Undergrad research	Research-oriented design team	Research-oriented internship/co-op	Undergrad thesis	Technical forum/conf. presentation	Other (please specify):
Robot	59.49%	26.28%	9.49%	19.34%	8.39%	5.84%	4.38%
Nano	40.68%	47.46%	13.56%	15.25%	8.47%	10.17%	5.08%
Overall	56.16%	30.03%	10.21%	18.62%	8.41%	6.61%	4.50%

Table 7: Question 5

	Please indicate your level of agreement with the following statement, "My experience in my ENGR 193/1282 project course helped me decide to get involved with research."				
Course Option	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Robot	11.83%	29.59%	40.83%	17.16%	0.59%
Nano	0.00%	7.69%	40.38%	44.23%	7.69%
Overall	9.05%	24.43%	40.72%	23.53%	2.26%

Table 8: Questions 6-7

	PRIOR to taking ENGR 193/1282, did you plan to attend graduate or professional school?		SINCE taking ENGR 193/1282, do you plan to attend graduate or professional school?	
Course Option	Yes	No	Yes	No
Robot	45.89%	54.11%	58.56%	41.44%
Nano	66.13%	33.87%	75.81%	24.19%
Overall	49.44%	50.56%	61.58%	38.42%

Table 9: Statistical values

Question	Q 1	Q 2	Q 3	Q 4	Q 5	Q 6	Q 7
p-value	0.000	0.042	0.000	0.055	0.000	0.004	0.0011

Discussion

As seen in Table 5 (Questions 1-3), a greater percentage of students who have completed the Nano option are interested in conducting research before taking the course, conduct research after taking the course, and intend on conducting research after taking the course. As seen in Table 6, Nano alumni have the most experience with research, specifically undergraduate research, with the exception of research-oriented internships and co-ops. This may be explained as students interested in research tend to conduct research at universities as compared to interning between semesters.

Table 7 (Question 5) most directly relates to the hypothesis, in which students attribute their involvement in research to their first-year engineering experience. Over 50% of students who completed the nanotechnology option either 'Agree' or 'Strongly Agree' and less than 50% are 'Neutral' or 'Disagree' that their experience helped them decide to get involved with research. This is contrary to over 40% either stating 'Disagree' or 'Strongly Disagree' that their experience in Robot helped them decide to get involved with research.

Table 8 (Questions 6 & 7) shows that the Nano option has the highest intended involvement in graduate and professional school both before and after taking the course. Both course options have an increase in intention to attend graduate/professional school.

Table 9 indicates statistical significance for all questions (significance set at $\alpha = 0.05$), with the exception of Question 4. The p-value indicates the probability that the two sample populations, Robot and Nano, would produce the same distribution of answers. The lack of significance for Question 4 can be partly be explained by the limited sample size of Nano alumni (62 students), as some choices had less than 5 expected responses (approx. 8% for Nano), and this limits the power of the Chi-squared test.

This class offers an alternative that meets the needs of students interested in research. The results of Question 1 suggest that students take the nanotechnology option because it better aligns with their interests; Question 3 suggests that they complete the class maintaining that interest, and Question 5 suggests that the class contributes to that continued interest.

Future Directions

The course has recently implemented the inverted classroom model. The course was successfully conducted last spring and will continue to be updated every year through the collaboration of faculty and staff of teaching assistants. For future years, the microfluidics portion will increase the freedom to test variables in the lab component, placing more emphasis on the experimental design. This will add variety to the poster competition and allow students to conduct and design more unique experiments.

This data has justified the motivations of this course, which trains a new generation of STEM researchers. Additionally, this course has positively influenced students' motivation to become involved with future research as an undergraduate and beyond. Research is necessary for the development of STEM fields, and it starts with education. This addresses the need for domestic students to continue education and support graduate and professional programs in the US.

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