Impact of a graduate elective in Microbial Soft Matter on interdisciplinary learning

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Abstract

This paper reports the finding that students made small increases in interdisciplinary learning through completion of a graduate elective course on bacterial biofilms that was designed and offered according to an interdisciplinary approach. The course enrolled students from multiple disciplines and was co-taught by two instructors with different disciplinary perspectives. As assessed through three surveys at different time points in the course, students increased their self-perceived ability to recognize disciplinary perspectives and teamwork skills; however, students made little to no changes in their interdisciplinary skills and reflective behavior over the course of the semester. The course contained students from chemical engineering, civil and environmental engineering, and microbiology and immunology. Through coding responses to homework assignments, we identified an increase in the use of engineering terminology in microbiology and immunology students as well as an increase in the use of microbiology terminology in engineering students. During the fourth week of the course only 27% of students used terminology in responses to a homework problem that predominantly related to both engineering and microbiology or a discipline other than their own, while in the fourteenth week of the course 64% of students utilized either interdisciplinary terminology or terminology from a discipline outside of their own to propose extensions of course projects. Overall, we have shown that a graduate course designed to improve interdisciplinary learning is capable of making small increases in the interdisciplinary learning of students.

Background

The need to create graduate students with interdisciplinary skillsets is regarded as increasingly important as research challenges become more complex and fall outside the disciplinary constructs of currently established fields. Interdisciplinary skills are desired within academia, government and industry. As a result, interdisciplinary graduate programs and interdisciplinary research funding are becoming more prevalent. A search of the active research funding opportunities at the National Science Foundation (NSF) reveals that ~40% (166/416) of programs with active funding emphasize or encourage interdisciplinary work[1]. Many schools offer specific graduate degree programs with an emphasis on a particular interdisciplinary area. Some schools are internally supporting the expansion of interdisciplinary research. One program that specifically supported interdisciplinarity in graduate student training was the NSF's Integrative Graduate Education Research Training (IGERT) Program to fund the training of graduate students. In 2010, Borrego et al. analyzed 94 IGERT awards and found that 80% of the programs proposed an interdisciplinary graduate course as a primary way to achieve interdisciplinary learning outcomes for students[2]. Thus, coursework is cited as a common means for creating interdisciplinarity within interdisciplinary graduate programs.

Beyond new interdisciplinary programs and funding opportunities, equipping students from engineering departments with interdisciplinary skills creates students that are ready to solve problems in new or emerging fields where the understanding of problems must extend beyond preexisting disciplinary boundaries. In the current work, we consider interdisciplinary learning

within the specific context of a graduate course in bacterial biofilms, a new research area that intersects a number of disciplines. Bacterial biofilms are multicellular structures responsible for the contamination and failure of many engineered systems and also play a central role in infectious diseases for humans, animals, and plants. Advancing the understanding of bacterial biofilms in engineered and biological contexts benefits from knowledge of the physical forces and fluid dynamics of the growth environment as well as the genetic pathways that lead to the production of biofilm matrix materials. Neither a traditional engineering view of the physics involved nor a life science view of the cell biology involved is sufficient for developing new strategies for mitigation and remediation of fouling by biofilms. While faculty may agree that interdisciplinary training would help in approaching complex problems that involve many disciplines, much of the university is structured around specific departments, schools, and colleges, and faculty are seldom encouraged to develop pedagogies related to interdisciplinary learning [3]. Therefore, student development of interdisciplinary skills may be limited. One way to increase student exposure to interdisciplinarity in these engineering departments is through graduate classes, such as the one in which this research occurred.

Through our work, we seek to understand the impact of a stand-alone interdisciplinary graduate elective course on graduate student learning. Specifically, we want to assess how students develop as interdisciplinary learners as well as the extent students use skills outside of their home disciplines during a semester long course. The context for our study is therefore a course titled Microbial Soft Matter, a topic that is inherently at the boundaries of microbiology and engineering. The course was specifically designed to foster interdisciplinary learning. There were two instructors from different disciplines teaching the course, and students from many departments across the university were invited to participate in the course. The course was organized into two segments. The first contained lectures and homework problems, and the material alternated between topics emphasizing microbiology and topics emphasizing engineering. The second segment focused on application of the material through group project work and real world examples of the material highlighted by external speakers. Throughout the course, students were encouraged to bring their own perspectives into discussions and relate the material across disciplinary boundaries.

To assess the impact of this course on graduate student interdisciplinary learning, we surveyed students at the beginning of the course, after the lectures, and at the end of the course. We also coded student responses to two course assignments. We evaluated how student perceptions of interdisciplinary learning outcomes varied from the beginning to the end of the course. Of additional interest was the extent that students applied information from another discipline to their coursework as well as any specific aspects of the course that contributed to changes in student-perceived interdisciplinary skillsets.

Using these methods of surveys and structured thematic analysis of written homework assignments, we measured the capacity of a graduate course to change measures of interdisciplinary thinking in a cohort of engineering and microbiology graduate students. Our work suggests that in one semester, students readily incorporate concepts from multiple disciplines into written work and increase their appreciation for different disciplines' perspectives. Measured student perception of teamwork behavior also improved, while other

features, specifically reflective behaviors and skills needed to work interdisciplinarily were not significantly impacted.

Methods

Course Description and Subject Population
We used a graduate level elective course listed in the chemical engineering department at the University of Michigan as a pilot study to advance the understanding of interdisciplinary learning. The course consisted of subject matter related to understanding bacterial biofilms, a topic at the interface of engineering and microbiology. The aim of the course was to provide students with skills to understand, analyze, and interpret research and technologies associated with bacterial biofilms that could be encountered in both research and industry. Topics covered in the class included relevant fundamentals from microbiology, fluid dynamics, and material science. The class was co-taught by a faculty member from the College of Engineering and a faculty member from the Medical School. The course consisted of two segments. The first segment (weeks 1-9) was made up of lectures and in-class problems, alternating between the two disciplinary perspectives, and the second segment (weeks 10-14) synthesized the understanding from the two disciplines through real world examples of the material highlighted by three external speakers as well as a required course project by each student.

Students were recruited by standard posting of the course description and through personal communications between the course faculty and graduate program directors within both the College of Engineering and the life science components of the Medical School, School of Public Health and College of Literature, Sciences, and Arts at the University of Michigan. There were 11 students enrolled in the course from the following disciplines: chemical engineering, civil and environmental engineering, and microbiology and immunology. There were also 4 students auditing the course, who did not complete course assignments, but completed the surveys. The demographics of the enrolled and auditing students are summarized in Table 1.

Table 1. Student Disciplines.

Department	All students N=15	Enrolled Students N=11
Chemical Engineering	8	6
Civil and Environmental Engineering	4	3
Microbiology and Immunology	3	2

Timeline of data collection
Quantitative data was collected from three surveys during weeks 1, 9, and 14 and qualitative data was collected from two student homework assignments from weeks 4 and 14. To ensure confidentiality of students, students were de-identified from their responses before presenting the data. Additionally, any data used in the study from student coursework was analyzed after the course had concluded. A schematic of the timeline of data collection is shown in Figure 1.
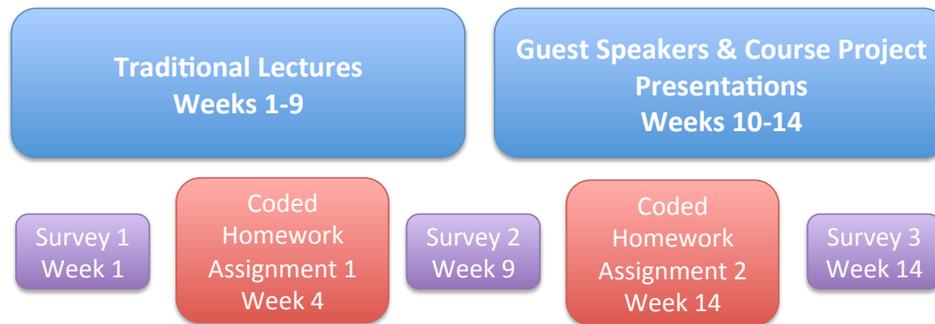
Figure 1. Timeline of course segments and data sampling.

Quantitative Data Collection and Analysis

Students were invited to participate in three IRB-approved online surveys via email to evaluate differences and similarities in student-perception of learning outcomes. The surveys were administered at the following time points: (1) during the first week of class, (2) at the conclusion of the lecture portion of the class, and (3) at the end of the semester. The surveys consisted of elements of an instrument created by Lattuca et al. in 2011[4]. The instrument of Lattuca et al. was initially used in a study to assess student learning outcomes related to interdisciplinarity in a nationally representative sample population of undergraduate engineering students[4]. The survey contained questions associated with interdisciplinary learning outcomes to establish if students' self-perception within any of four domains: interdisciplinary skills, recognizing disciplinary perspectives, reflective behavior or teamwork skills changed over the duration of the course. Lattuca et al. developed the questions in each of these domains through a rigorous, two year process that included a thorough literature review, individual and focus-group interviews, and the use of the Cronbach's α as the indicator of the internal consistency reliability of the four subsets of interdisciplinary questions (all Cronbach's α values were greater than or equal to 0.69 [4]). The Cronbach's α is a measure of how closely related a set of items are as a group and ranges from 0 to 1; values greater than 0.7 are considered to have good internal consistency. The interdisciplinary skills section of the survey included questions on the self-perceived extent that students do the following: value reading about topics outside of their field, enjoy thinking about how different fields approach problems, think about if problems have non-technical solutions, seek information from experts in other fields, figure out ideas that are appropriate for solving a problem, see connections between ideas in their field and ideas in other fields, take ideas from outside of their field and synthesize them to solve a problem, and use ideas from another field to solve a new problem. The recognizing disciplinary perspectives domain includes questions on the extent students recognize the kinds of evidence that different fields rely on, identify the kinds of knowledge and ideas that are distinctive to different fields of study, and are good at figuring out what experts in different fields have missed in explaining a problem or proposing a solution. Reflective behavior contains questions on the degree students stop to think about where they are going right or wrong with a problem solution, and step back to reflect on what they are thinking to determine whether they may be missing something. Students also rated teamwork skills based on their self-perceived ability to do the following: work in teams of people with a variety of skills and backgrounds, work with others to accomplish group goals, work in teams where knowledge and ideas from multiple fields must be applied, work in teams that include people from fields outside of their field of study, and put aside differences within a design team to get

work done. These four subsets of questions had previously been correlated to interdisciplinarity[4]. The specific survey elements used in this study are found in Appendix 1.

Survey items for interdisciplinary skill, recognizing disciplinary perspectives, reflective behavior, and teamwork were averaged across domain for each student. Baseline differences in these features were compared across student discipline (i.e., chemical engineering, civil and environmental engineering, and microbiology and immunology) using one-way analysis of variance. Clustering between student types was further compared with principal component analysis. Changes in features over time were examined using linear mixed effects models assuming that the three survey times (baseline, mid-semester, final) were equally spaced in time and that any changes over time in student characteristics were linear. The mixed effects model included survey time point and student type and used student identity as the random, repeated effect. Analysis was performed using the base and NLME packages in R 2.13.2 [5, 6].

Qualitative Data Collection and Analysis
We coded responses from two homework assignments collected during the term to determine if student responses to open-ended questions relied primarily on knowledge related to their major field of study or if students began to apply knowledge from another discipline. The assignments were analyzed using grounded theory, where patterns and theory are grounded in observation and developed from the data collected. We began coding by performing open coding, where the whole body of data was read and words that captured key concepts were highlighted [7, 8, 9]. The highlighted concepts focused on clearly observable characteristics of the student responses [10]. We then used axial coding to reanalyze the results of the open coding and label general concepts or categories that were reflective of one or more of the initially identified key concepts [7, 9]. Finally, we used selective coding to link the open and axial codes to central concepts or phenomena [7, 9]. In our case, the central concepts were trends in the responses related to engineering, microbiology or the interdisciplinary intersection of the two fields. The coding process was iterated and student assignments were reread until no new codes emerged from the data [11].

A single coder coded all assignments and a second coder coded approximately 50% of the assignments. Reliability of the coding scheme was verified through comparing codes from assignments coded by both coders. Based on initial coding of the two assignments, coders reached agreement on codes for 83% of the responses. For the cases where coders disagreed, they settled discrepancies by mutual agreement until 100% of the responses were agreed upon.

The first homework assignment was from the first segment of the course and relied on student understanding of bacterial adhesion, a topic at the interface of engineering and microbiology. The problem could be answered with a response related to physical interactions between bacteria and the environment or specific behaviors of the bacteria such as the production of matrix materials or quorum sensing molecules. Thus, key words could be pulled from the assignment and coded as engineering or microbiology terms. Using the key words, we could then determine if a response contained content related primarily to engineering or microbiology.

The second coded homework assignment was a reflection on two of the oral course project presentations that were completed by students. The reflection assignment included a summary of

the project, and a discussion of how the project could be extended. We coded the assignment in two ways. First, we coded the descriptions of the two projects chosen for the assignment. We determined if the language used to describe each of the projects was predominantly related to engineering, microbiology or at the interface of the two for each student. Second, we coded the ideas students had to extend or continue projects that had been presented by their peers. We determined if the language used to describe the new ideas was interdisciplinary or related mainly to engineering or microbiology.

Results

Quantitative Analysis
We surveyed students to determine self-perceived changes in four different categories of interdisciplinarity: interdisciplinary skills, recognizing disciplinary perspectives, reflective behavior, and teamwork. We determined that there were no significant differences in the baseline averages across student type: chemical engineering, civil and environmental engineering, and microbiology and immunology as indicated by $p > 0.05$ between student group averages in all four categories of interdisciplinarity. The baseline data are tabulated in Table 2.

Table 2. Baseline Interdisciplinary Features of the Cohort

	Chemical Engineering	Civil and Environmental Engineering	Microbiology and Immunology	P value (by ANOVA)
Interdisciplinary skills	3.6 (3.5, 4.3)*	3.9 (3.9, 4.0)	4.0 (3.8, 4.2)	0.82
Recognizing disciplinary perspectives	3.0 (2.4, 3.6)	3.5 (3.3, 3.7)	3.0 (2.7, 3.5)	0.53
Reflective behavior	4.0 (4.4, 4.5)	4.0 (3.8, 4.5)	3.5 (3.3, 3.8)	0.25
Teamwork skills	3.1 (2.8, 4.2)	3.4 (3.1, 3.6)	3.8 (2.9, 3.9)	0.97

* Presented as median and interquartile range

Clustering between student types was analyzed using principle component analysis. No significant clustering was found, indicating that the students at the baseline responded very similarly across disciplines, as shown by Figure 2. The features that loaded most heavily into the two principle components were teamwork (component 1, -0.841) and recognizing disciplinary perspectives (component 2, 0.946). The other component loadings are summarized in Table 3.

We determined that student self-perception of recognizing disciplinary perspectives and teamwork skills increased over the course of the semester for all student groups. However, there was no significant increase in interdisciplinary skills or reflective behavior, as shown in Figure 3.
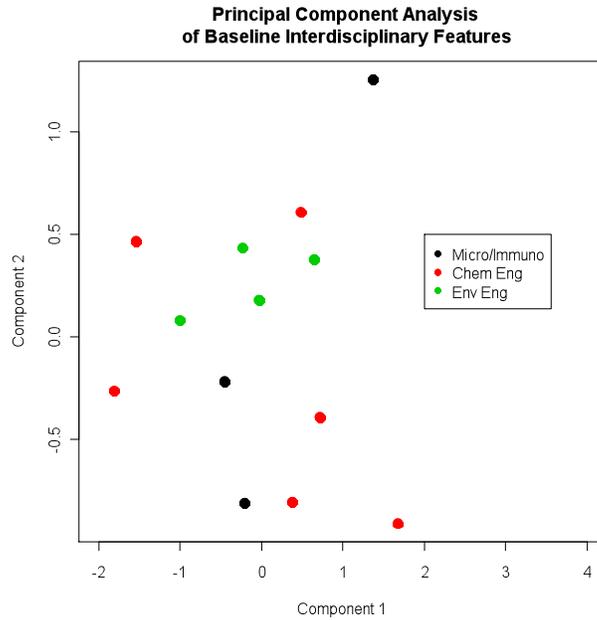
**Principal Component Analysis
of Baseline Interdisciplinary Features**

Figure 2. Principal component analysis of student features shows that students in general were very similar across discipline, and no significant clustering was observed.

Table 3. Loadings of Four Interdisciplinary Features on Principal Components

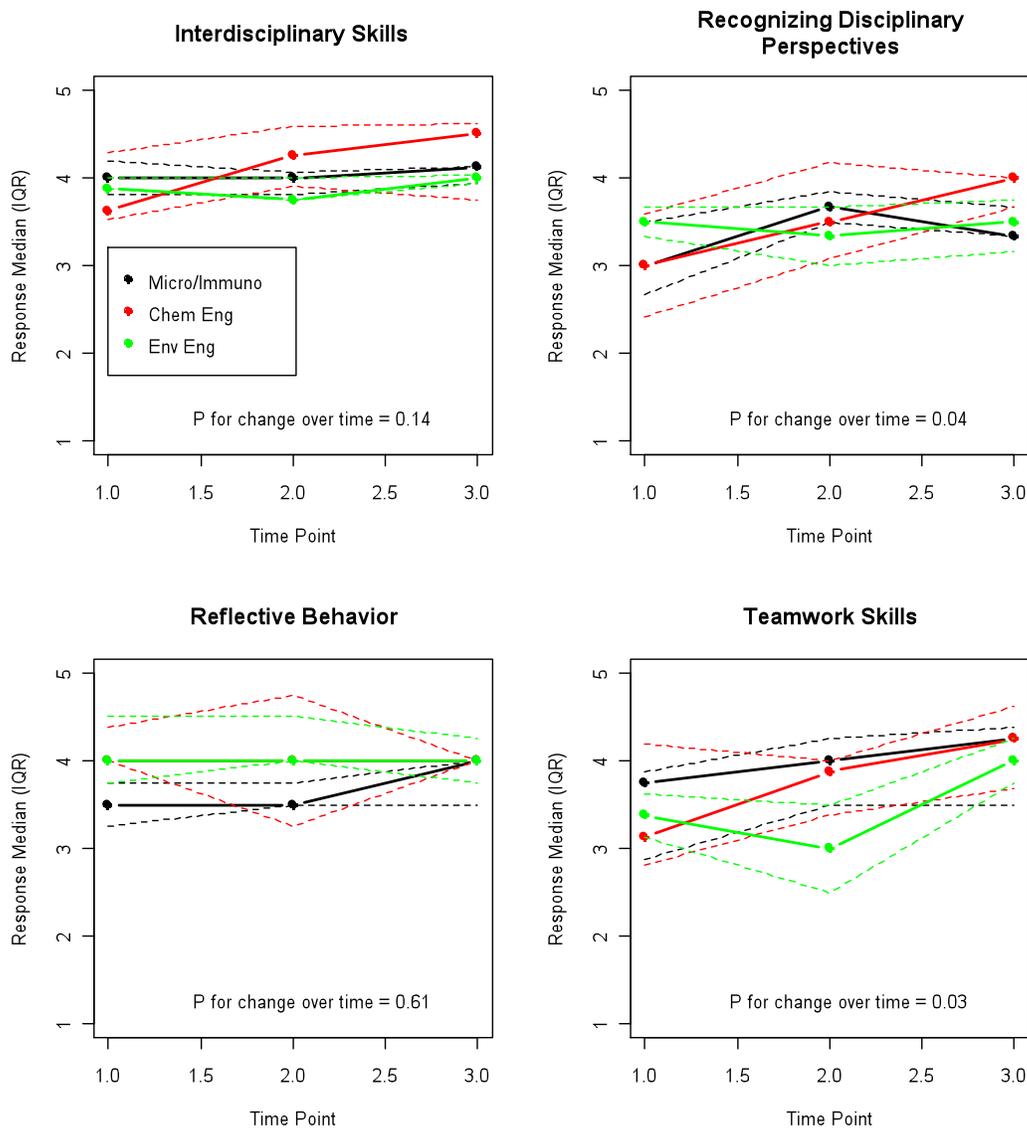|	Component 1	Component 2	Component 3	Component 4
Interdisciplinary Skills	-0.341		0.319	0.881
Recognizing disciplinary perspectives	-0.238	0.946	-0.188	-0.113
Reflective behavior	-0.348	-0.238	-0.883	0.208
Teamwork skills	-0.841	-0.203	0.289	-0.411

Figure 3. Changes in student characteristics over the course of the semester. Increases were seen over the semester in recognizing disciplinary perspectives and teamwork skills, both of which were statistically significant using linear mixed effects modeling. In no domain was student discipline statistically related to interdisciplinary skills or reflective behavior (p > 0.05 for each). Data expressed as mean (bold line) and upper and lower quartiles (dashed lines).

Qualitative Analysis
In addition to surveying students, we coded responses from two assignments during the semester. The first assignment was from the fourth week of class during the lecture-based portion of the course and between the first and the second survey. The second assignment was due the fourteenth week of the course after the project presentations, and between the second and the third survey.

For the first assignment, 82% of students used some information from outside of their field to answer the question, while 18% of students (2 engineers) used information solely from their field. 18% of students (one engineer and one biologist) gave responses related predominantly to biology, 64% of students gave responses related to engineering, and 18% of students gave interdisciplinary responses. 64% of students provided responses where the majority of the response was grounded in their primary discipline. Additionally, 36% of students used literature outside of their discipline to extend their knowledge of the topic. Codes used to classify words related to microbiology or engineering are summarized in Table 4.

Table 4. Summary of codes for assignment 1.

Central Concept	Coded words

Engineering	a. Physical interaction
	    i. van der Waals
	    ii. Electrostatics/charge
	    iii. Refractive Index
	    iv. Gravity
	    v. DLVO
	    vi. Brownian motion
	    vii. Cell-cell interaction
	    viii. Surface charge
	    ix. Surface roughness
	    x. Depletion
	    xi. Forces
	    xii. Potential energy
	    xiii. Hydrophobicity/ Hydrophobic/ Hydrophilic
	    xiv. Hydrogen bonding
	    xv. Steric effects
	    xvi. Osmotic interactions
	    xvii. Bacterial size
	    xviii. Solvent properties
	b. Covalent bonding
	c. Fluid Dynamics
	    i. Convection
	d. Motility*
	    i. Random Walk
	    ii. Swimming
	    iii. Swarming

Microbiology	a. Matrix Materials
	    i. Polysaccharides
	    ii. Secreted polymers
	    iii. Extracellular polymeric substances
	    iv. Capsule
	    v. eDNA
	    vi. Proteins
	    vii. Glycoproteins
	    viii. Glycolipids
	    ix. Components of clotting cascade
	b. Nutrient-limited environment
	c. Quorum Sensing
	d. Gene Expression
	e. Other adhesive organelles Pili, curli, and fimbriae
	f. Motility*

*Motility could be coded as engineering or microbiology related depending upon the use within the assignment.

For the second assignment, the first portion of the assignment involved describing two of the seven oral project presentations that were given by students. Three students worked

independently and eight students worked in groups of two. Thus, three presentations were given by individuals, and four presentations were given by pairs of students. Presentation topics were selected based on students interests and are summarized in Table 5. 82% of students used predominantly language relating to both engineering and microbiology or language from a discipline outside of their own to describe at least one project, indicating interdisciplinary responses to the assignment from the majority of the class when describing project presentations. The second part of the assignment was to propose an idea that extended upon the ideas of the project presentation. For the second part of the assignment, 64% of students proposed at least one project extension idea outside of their discipline. However, since each student proposed 2 projects, only 41% of the 22 proposed project extensions involved ideas outside of the student's discipline.

Table 5. Summary of project topics and group compositions.

Project Title	Group Composition
Proteins in biofilms: a brief look at the biofilm-associated protein	1 Microbiology & Immunology student
Forces governing motion, adhesion, and clearance of rod-shaped bacteria	1 ChE student
DLVO analysis of the effect of surface material, geometry, and roughness on bacterial adhesion	1 ChE student
An enhanced wastewater treatment system: optimizing cellulose digestion using ruminant fungi	2 ChE students
Biofilm formation by methanotrophs	2 CEE students
COMSOL simulation of bacteria absorbing in a biofilm	1 ChE student & 1 CEE student
Prevention and treatment of dental plaque	1 ChE student & 1 Microbiology & Immunology Student

Summary and Discussion

Through our work, we have shown that small increases in interdisciplinary learning have occurred through a graduate elective course on bacterial biofilms that was designed and offered with the intent of increasing interdisciplinary learning at the boundary of engineering and microbiology. The initial responses to survey questions were very similar across disciplines for all students in the course. This may be due to the nature of the type of student that chose to enroll in an interdisciplinary course. When the data were analyzed with respect to time, the only categories of interdisciplinarity with significant increases with respect to time were the dimensions of recognizing disciplinary perspectives and of teamwork. Interestingly, these were the same features that loaded heavily into the two principle components.

Qualitatively, based on the assignment coded from the first half of the class, students began to use information from outside of their field in a homework assignment (82%); however, the majority of students (73%) gave responses that were predominantly grounded in their discipline. Also, some students began to utilize external resources to extend their knowledge of the topic beyond their discipline (36%). Thus, students were open to reaching across disciplines to extend

their knowledge base. However, the majority of students were not coming up with interdisciplinary responses that depended equally on both fields or learned from the discipline outside of their own.

Qualitatively, from the assignment coded from the second half of the class, the percentage of students describing at least one scenario outside of their field remained the same (82%). However, 64% of students proposed at least one new idea related to extending projects outside of their discipline. This is a significant increase compared to the 27% of students that utilized predominantly descriptions outside of their field or interdisciplinary descriptions in the first assignment.

Overall, we have shown that a single offering of a graduate elective on bacterial biofilms that was designed to promote interdisciplinary learning increases the interdisciplinarity of students from both engineering and microbiology in the areas of recognizing disciplinary perspectives as well as teamwork. We did not observe significant changes in interdisciplinary skills or reflective behavior. We also saw an increase in the use of key words and terminology outside of the student's core discipline when comparing an assignment from the first and second half of the course. The sample size for the qualitative piece of our study was 11 students. Determining if the findings from this single classroom of students hold true within classes with larger numbers of students as well as in different interdisciplinary classes is necessary to prove how stand alone interdisciplinary graduate courses impact interdisciplinary student learning; however, this study offers a preliminary look at the impact of a graduate elective course on interdisciplinary student learning.

This work contributes to advancing the understanding of graduate education in an increasingly interdisciplinary climate. It shows that a course intentionally designed to promote interdisciplinarity, with many attributes that would be commonly considered to promote interdisciplinarity, such as students drawn from multiple disciplines, instructors with different disciplinary perspectives, and assignments designed to promote collaboration across disciplines, still only yields modest gains in common measures of student interdisciplinarity. It therefore suggests the limits of these common approaches, and provides motivation to develop new ideas to promote this important skill for graduate education.

This study served as a pilot study on interdisciplinary learning in a graduate course. Expanding this study to multiple courses to see if the results from other courses are in agreement with our findings would allow for a more general understanding of the extent to which interdisciplinary courses with intentionally designed interdisciplinary elements are successful at creating interdisciplinary learners. Additionally, an investigation of the effect of using different methods to cover course material on interdisciplinary learning such as traditional lectures, commonly accepted methods that aim to promote interdisciplinarity, or newly developed methods for interdisciplinary learning would be an excellent expansion of this study. Furthermore, there is space to investigate differences between student learning in interdisciplinary courses and non-interdisciplinary courses with students from a variety of different majors. This work served as the initial step for investigating interdisciplinary learning within graduate elective coursework.

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Appendix 1: Survey elements for assessment of student learning outcomes related to interdisciplinarity.

* The below survey elements are taken from Lattuca et al. (2011). *ASEE Annual Conference and Exposition.*

Do you agree or disagree with the following statements?
(1: Strongly disagree; 2: Disagree; 3: Neither agree nor disagree; 4: Agree; 5: Strongly agree)

Interdisciplinary Skills
1. I value reading about topics outside of my major field of study.
2. I enjoy thinking about how different fields approach the same problem in different ways.
3. Not all problems have purely technical solutions.
4. In solving problems, I often seek information from experts in other academic fields.
5. Given knowledge and ideas from different fields, I can figure out what is appropriate for solving a problem.
6. I see connections between ideas in my field of study and ideas in the humanities and social sciences.
7. I can take ideas from outside my field of study and synthesize them in ways to better understand a problem.
8. I can use what I have learned in one field in another setting or to solve a new problem.

Recognizing Disciplinary Perspectives
1. I recognize the kinds of evidence that different fields of study rely on.
2. If asked, I could identify the kinds of knowledge and ideas that are distinctive to different fields of study.
3. I'm good at figuring out what experts in different fields have missed in explaining a problem or proposing a solution

Reflective Behavior
1. I frequently stop to think about where I might be going wrong or right with a problem solution.
2. I often step back and reflect on what I am thinking to determine whether I might be missing something.

Please rate your ability to:
(1: Weak/None; 2: Fair; 3: Good; 4: Very good; 5: Excellent)

Teamwork Skills
1. Work in teams of people with a variety of skills and backgrounds.
2. Work with others to accomplish group goals.
3. Work in teams where knowledge and ideas from multiple fields must be applied.
4. Work in teams that include people from fields outside your field of study.
5. Put aside differences within a design team to get the work done.