Teaching Across Boundaries: Examining the Institutional Process of Establishing Multidisciplinary Courses

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Abstract: Many of the decisions educators make are under direct influence of institutional structure, notably those that seek to create multidisciplinary spaces for students. Some multidisciplinary courses are developed in isolation even though they are intended to combine and integrate disciplines. This study seeks to explore how such multidisciplinary courses are established --the process that educators undergo to design and implement these courses, both formal and informal. We aim at utilizing social network analysis to identify and communicate the connections between educators and their multidisciplinary courses such that future courses can be developed more strategically. We have mapped the formal structure of the College of Engineering at Southeast R1 University using social network analysis and created networks representing the faculty involved in co-taught courses. To supplement the publicly available data, we conducted semi-structured interviews with faculty affiliated with a broad sample of the multidisciplinary courses. Our analysis compared the themes that emerged from interviews against those from the social network analysis. These analyses enabled us to identify instances of alignment and divergence between what was shown in the institutional data and what was perceived and explained by faculty directly involved with disciplinary courses. Findings of this work can serve departments and educators by acting as a feedback loop in providing new avenues for creating and implementing multidisciplinary courses by utilizing existing multidisciplinary connections.

Keywords: multidisciplinary, social network analysis, institutional barriers, co-taught courses

Introduction

There is an increasing call for interdisciplinarity and transdisciplinarity at the university-level [1], [2], yet with less direct change in the avenues in which these calls can be heeded [31]. Transdisciplinarity is perhaps the most recent conceptualization of engaging students across disciplines to solve 21st century, real-world challenges. Funding for interdisciplinary research has risen as agencies pour resources into avenues that will enhance their global competitiveness [1]. In the context of U.S. undergraduate engineering education, the Accreditation Board for Engineering and Technology (ABET) has required that students meet outcome 3.d which is the ability for graduates to function on multidisciplinary teams [2]. External drivers are pushing multi-, inter-, and transdisciplinarity into higher education, but there are layers of internal webbing that are rarely explored when raising calls for more interdisciplinary learning and collaboration.

In the most recent MIT report, The Global State of the Art in Engineering Education, Ruth Graham highlighted a "focus on rigor in the engineering fundamentals" but also "user-centered design, technology-driven entrepreneurship, [and] active project-based learning" [3]. A key challenge that constrains engineering schools is their "siloed monodisciplinary structure… and faculty appointment and promotion systems that are not perceived as rewarding teaching achievement" [3]. In the MIT report, Graham anticipates a shift "towards socially-relevant and outward-facing engineering curricula" in which "curricula emphasize student choice, multidisciplinary learning, and societal impact" through student experiences that lay "outside traditional engineering disciplines" [3, p. 39]. The integration of these educational features is what is currently lacking, as they may be included in engineering programs but generally as afterthought activities engineered to tick boxes for accreditation [3], [4].

Individual faculty have undertaken efforts to provide more opportunities for students to broaden their education through multi- and interdisciplinary design-related courses that engage student teams in complex socio-technical problems [5], [6], [7]. However, there are many institution-specific challenges that faculty navigate when developing and implementing courses that diverge from traditional content-heavy lectures [8], [9]. Additionally, as enrollment continues to increase due to an increasing dependence on student tuition as a funding source for higher education institutions, many of the current issues for the undergraduate curriculum revolve around how to serve a larger cohort [2]. Engineering education seeks to improve and sustain sequential integration across courses and provide courses that help students develop as holistic engineers [10], [11], but making these changes for an increasing student population is an added challenge.

Background

Multidisciplinarity, Interdisciplinarity, and Transdisciplinarity

Multidisciplinarity, interdisciplinarity and transdisciplinarity learning are difficult objectives to incorporate into course goals, often because faculty have different understandings of what the terms imply [11], [12]. The interchangeable use of terms contributes to the ambiguity that they have come to hold, which can act as a barrier to faculty collaboration in achieving this quality in the classroom. Multidisciplinarity is defined as the combination of disciplinary content, an example being the construction of a building – the team involved with water utility infrastructure is not involved in that of the electrical features. Each discipline-specific aspect of the building is conceptualized and created in isolation and then combined for a final product. Interdisciplinarity is defined as the integration of disciplinary knowledge, which could be conceptualized as a building in which the air ventilation features have been developed in tandem with the structural features such that they work to enhance one another. Transdisciplinarity, perhaps the most ambiguous, crosses disciplinary boundaries to sit at the critical point of a new discipline entirely [7]. Yet, these definitions can be discipline-specific in and of themselves and can vary based on the disciplinary lens from which they are used. Combining versus integrating disciplinary content can be difficult for instructors teaching a course intending to cross disciplinary boundaries, especially in its first implementation. Iterative tweaks and changes are necessary for courses to improve and faculty to learn.

However, there are institutional challenges in the design and implementation of interdisciplinary courses that faculty often face when working in a space that indirectly punishes those for trying [7], [12], [13], [14]. As an example, the traditional requirements that govern one department's course may not coincide with those from another. Disciplines encompass the bounds by which "we construct and organize knowledge" and adhere to a specific "set of standards and level of rigor" [20, p. 48]. These discipline-specific standards of rigor contribute to academic institutional structures that affect the paths that faculty take to design and implement courses that encompass more than one discipline. Additionally, departments vary in how they count co-teaching toward teaching load and credit-hour budgeting, which can add another layer of complexity when courses are intended to be interdepartmental. Some departments have influential external forces such as accreditation or industry needs which can drive many of the changes in the curriculum and deter collaboration with departments that have different forces acting on them [21]. Departments may also be less inclined to support faculty-driven courses that take them away from research and departmental teaching responsibilities.

Faculty-Driven Courses in Engineering

One example of a faculty-driven course is a design studio taught by an Arts Education and Environmental Engineering professor [6]. The authors maintain that the integration of the Arts into the STEM (STEAM) course "provided a space… to dig deeper and make personally relevant connections between materials, design, society, and the natural environment" [6, p. 21]. The impact that the studio course was perceived to have on the students may be one driver for faculty to continue to teach the course. Additionally, the multiple publications describing the course show how the faculty members used the interdisciplinary course for research [6], [15] [16].

From the faculty reflections from course published by Sochacka and colleagues [6], the instructors speak of their openness to learning more about each other's fields as well as the discomfort that came with it. Through the design studio, the authors state that in working together, they questioned "the values, beliefs, and understandings [they] hold of [their] disciplinary selves and of each other" [6, p. 19]. From an institutional perspective, it can be difficult for faculty to sustain an arts and engineering course due to the inequality of departments regarding size, funding, or hiring abilities [18]. The arts can be marginalized in an engineering context, wherein the arts are used to spur economic innovation [15], [16]. These power differences can make it difficult to sustain a course that integrates arts and engineering because of the underlying value systems of the departments. For example, the course may be difficult to maintain if new faculty members inherit the course or department heads change [17]. Consequently, standalone courses without institutional support structures in place can be difficult to sustain once instructors leave or can no longer champion the course.

The pervasive culture across the institution makes it so that only a select few faculty members are in the position to pursue interdisciplinary research or teaching–those who feel the safety of tenure or those who believe that their interdisciplinary work is an asset in their bid for tenure [12]. However, this view on interdisciplinary teaching and research as a pre-tenure faculty is largely dependent on the culture of disciplines. In some disciplines, staying within one's discipline for research and teaching is more rewarding in the promotion and tenure process [12], [31]. In the case of a course seeking to integrate business, industrial design, and engineering, the faculty team described the course design as requiring a pragmatic but creative approach in "muscling through governance" to cross-list the course in the three departments [14]. When institutional structures inhibit faculty from designing and implementing courses that defy tradition, undergraduate education will also suffer [19].

Social Network Analysis

Social network analysis has been used extensively to study the structure of higher education, particularly at the faculty level [22]-[23]. Faculty networks have been studied frequently in higher education largely due to the fact that faculty members on average remain at institutions longer than students. This happens for many reasons, faculty may be able to influence the culture of the institution more due to their longer tenure, the relatively obscure and individualized nature of teaching courses, and the higher autonomy of faculty members in higher education. Coburn, Choi, and Mata, in an examination of a district-based math reform, emphasized the importance of teachers' social networks as "an important part of the school improvement puzzle" [22, pg. 60]. They went on to describe that faculty members facilitate the transfer of knowledge regarding research, pedagogy, and organizational issues that other methodologies cannot fully grasp [22]. Social networks have been vital in learning how faculty members are influenced by their peers in adopting and developing new technologies and instructional practices for their classrooms, as they present a method of visually presenting the informal structure of higher education [23]-[27]. Networks have also been utilized in explaining how faculty knowledge and innovation transfer and flow throughout departments. Social, informal connections instill trust between colleagues, which can create buy-in to an otherwise unwanted institutional change. Interactions among faculty are a valuable but often overlooked commodity of higher education [28].

In examining interdisciplinary student learning, Rienties and Heliot found that the social ties formed among graduate students in the first four weeks of a course were indicative of social ties later on in the course [29]. Over the course of the 11-week module, students primarily discussed with and learned from students of the same discipline, even when instructors balanced the teams with interdisciplinary students. Social networks provide a methodology for researchers to more adequately understand if students are learning interdisciplinarily, as this shows that it may not happen naturally. However, at the core of the problem is not that faculty do not know how to teach across disciplines, as many of them do, but that there are institutional barriers that faculty must overcome to design and implement interdisciplinary courses [7], [12].

Research Aims:

The aims of this study are to explore how multidisciplinary courses are established by way of formal and informal processes that educators undergo in their design and implementation. We use social network analysis to identify these connections between faculty involved in multidisciplinary courses such that future courses can be developed more strategically in undergraduate engineering.

Research Questions:

1. What are the formal institutional ties between faculty across departments?
2. How do the formal institutional ties compare to the development of co-taught courses?
3. How do faculty members experience teaching multidisciplinary, co-taught courses?

Methods

Setting and Participants

The study took place in a large research university in the Southeastern region of the U.S. The setting was limited to faculty in the College of Engineering, which has a total of 560 tenure-track and non-tenure track faculty across 12 engineering departments. Data were collected in the Fall of 2018 and Spring of 2019, respectively. IRB approval was obtained for this study.

Network Data Collection and Analysis

Data collection was performed in three ways so as to identify formal connections among faculty in the College of Engineering and to explore qualitative themes regarding the courses. For formal connections, publically available institutional data were collected from course registration sites for students as well as from undergraduate advisors in the College of Engineering. Formal connections among faculty were defined by the following criteria:

1. Courses that are co-taught by faculty from different departments as listed on the course description as having more than one instructor.
2. Courses that are co-listed by departments as listed on the course description to have more than one departmental prefix.
3. Departmental affiliations listed on publicly available institution-related websites.

Holistic Social Networks

There are two primary approaches to creating networks, each of which has varying use and purpose. This first of these is a holistic network, which depicts an entire community and looks for large-scale, observable patterns among the actors and ties [25]. The second type of network is known as an egocentric network, which focuses on an individual actor within a network, investigating various personal and relational characteristics of the actor [25]. In this study, the actors are those faculty involved in within the College of Engineering, with an emphasis on those involved with co-taught courses.

Holistic networks were created with publicly or institutionally available information to determine the departmental association and nature of the recent teaching experiences of each faculty member. The actors within the networks included but were not limited to tenured faculty members, non-tenure faculty members, adjunct faculty, and affiliate faculty. Faculty were connected to all other faculty affiliated within a given department, under the assumption that they all might have had some contact, whether at a department meeting or various other departmental activities. The purpose of the department network is to outline the formal ties that faculty members have that span departments, which from an institutional perspective might be one important tool for understanding the multidisciplinary nature of the college. Within the instructional network, faculty were connected to those that were listed as instructors for a given section of a course. The purpose of the instructional network was to understand the multidisciplinary nature of instruction in the College of Engineering, as gathered through institutionally available data.

Network Creation

To create the formal departmental network, a list of 560 faculty from the College of Engineering was collected to create a series of nodes. Formal department listings were taken from each department's respective university website. The color of each node represents the primary departmental faculty affiliation, while connections to other colored nodes represent other affiliations. For faculty with multiple affiliations, the primary department was used for the network node color. Ties were then created between all faculty affiliated with the same department. To create the co-teaching network, a list of nodes was created of the 560 faculty interwoven into the college of engineering. Institutional course registration for the 2018-2019 academic year were then gathered. Ties were created between faculty if they were listed as having taught a section of a course together in the given time period. In line with the formal faculty affiliation network, the color (attributes) of the faculty nodes remained the same as the departmental course listings, according to their primary department. To create the visualization for each network, a matrix was created in Excel, in which every faculty member in the College of Engineering represented a row and column. A "1" was placed in every cell to represent a connection between faculty and a"0" was placed to represent the lack of a connection. This matrix was then translated into UCINET software which visualized the matrix as a series of nodes and ties.

Qualitative Data Collection and Analysis

The qualitative inquiry was pursued through faculty interviews to offer more context regarding established co-listed and co-taught courses. The faculty were selected from the sample collected in the formal data collection. Due to the limited number of conducted interviews, the qualitative themes detailed in the findings are to contextualize specific course examples as they relate to the University at large. As a limitation of the methods, these interviews serve as exploratory insights into the formal connections and warrant further participants to supplement a wider sample of courses.

Four faculty members were interviewed, one of which is in the College of Natural Resources and Environment and the remaining three are in the College of Engineering. The interviews were semi-structured as to allow the nuances of the course evolution to come through. The interviews were audio-recorded and transcribed. They were open coded for themes regarding the development of the course and the iterative changes that have occurred in relation to faculty experience and changes across the university. The insights from the interviews were member checked with the participants to ensure the trustworthiness of the findings. The interviews served to add context to the process of establishing multidisciplinary courses, but serve as individual examples and are not intended to represent the breadth of faculty experiences who establish multidisciplinary courses. Additionally, the departments of the interviewed faculty have been generalized to their college or school, so as to maintain the anonymity of the participants.

University-wide Initiatives

General Education Curriculum. This Southeast R1 University has recently revised the general education curriculum to improve integration across courses. In the new model, each course has one of two common learning outcomes -- ethical reasoning or intercultural and global awareness. By threading a set of common learning outcomes across all the general education courses, the integrated curriculum improves students' ability to integrate their learning across their courses. To implement the new curriculum, faculty propose and offer short-term pilot sections of the new integrated courses. Those faculty could then act as mentors for future faculty intending to propose appropriate courses. Consequently, this system acts as a way to connect courses through common student learning outcomes as well as faculty collaboration in the mentorship of course design and implementation.

Institutional Transdisciplinarity. The other university initiative pertinent to this study is the university-wide push for transdisciplinarity. The university has chosen a collection of cross-disciplinary complex problems around which to cluster faculty research and teaching efforts. The formulation and implementation of these nine areas are an example of a top-down university initiative towards transdisciplinarity. In these areas, faculty and students are brought together to identify and solve complex problems that span disciplines. The stakeholder teams for each area have been able to hire faculty engaged in the area's research. Additionally, each area has a curriculum team that has been creating undergraduate minors through the general education structure detailed above. These minors consist of existing courses across disciplines and newly created courses that fit in with the area's mission.

Network Findings

Formal Networks

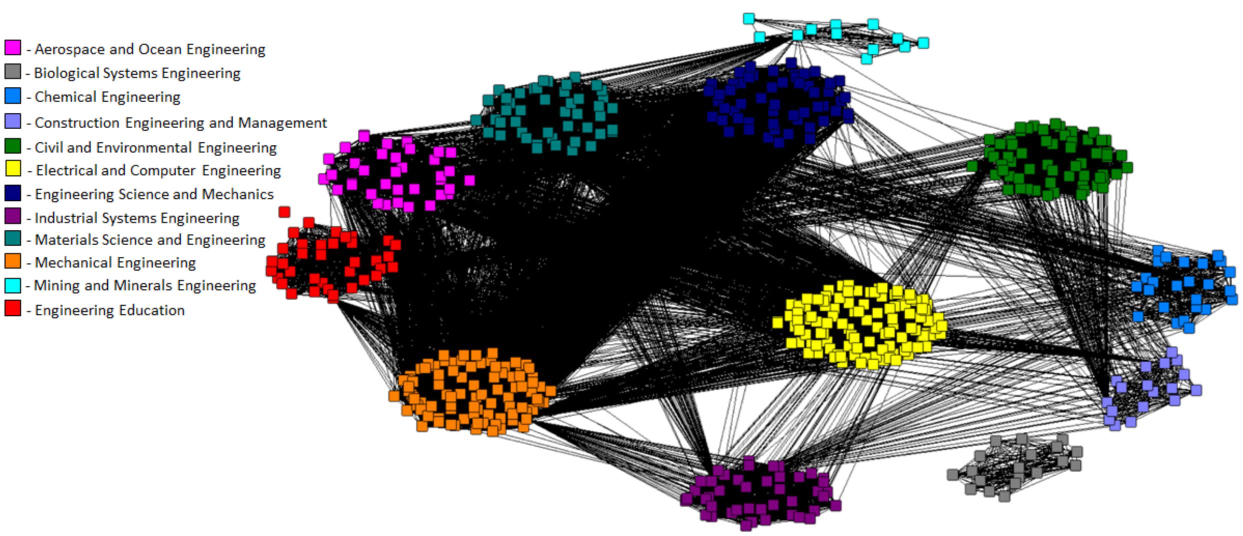

Figure 1. Formal Department Appointments

The network in Figure 1 represents formal department appointments and is comprised of a series of *nodes* and *ties*. The nodes represent faculty members in engineering departments at one institution, where each square represents a different faculty member. The colors represent the primary affiliation of faculty members across engineering departments. The affiliated faculty size for each of the 12 departments shown above ranges from 12 to 116. The ties, represented by black lines, represent formal connections among faculty across departments. Ties were created among all faculty members that were listed within a department. As a result of this mechanism, faculty with primary affiliations with a given department were grouped more closely than affiliated or non-related departments. Faculty with multiple department affiliations can be seen above connecting the large departmental hubs. Of the 560 faculty, over 70 (12%) of the faculty members were affiliated with more than one department. Departments such as Engineering, Science, and Mechanics (ESM) and Mechanical Engineering (ME) have 35 and 44 ties with other departments, respectively. While ESM and ME are the most connected departments, a majority of their ties (26) are shared between the two departments. On the other end of the spectrum, not all departments have formally moved towards multidisciplinarity. The Biological Systems Engineering (BSE) and Mining and Minerals Engineering (MME) departments have 0 and 1 ties with other departments, respectively.

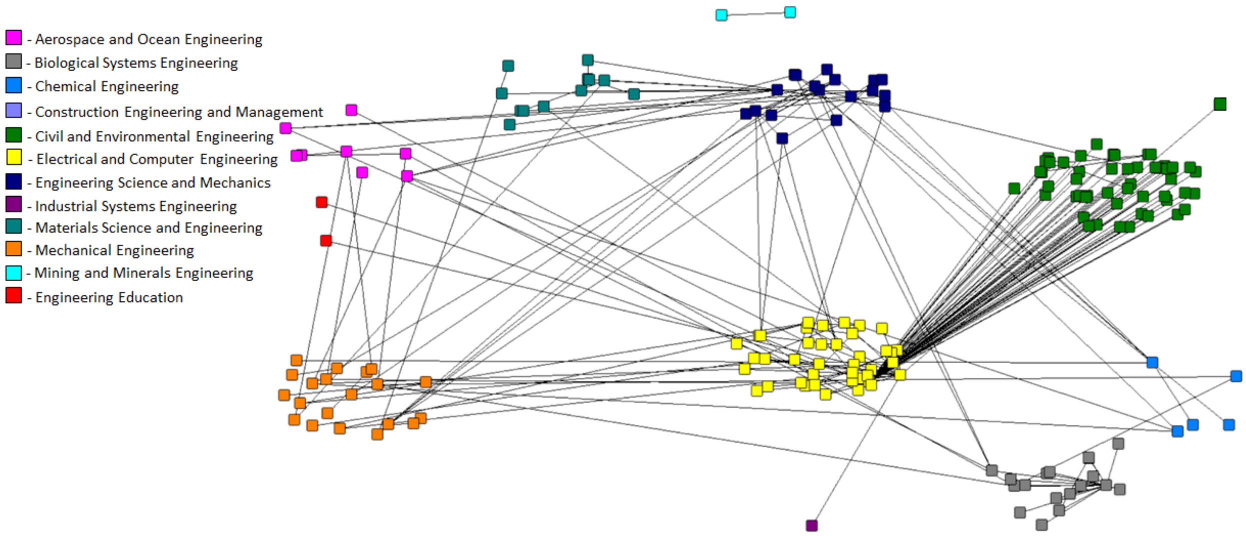

Figure 2. Formal Co-taught (Fall 2018 & Spring 2019)

The network in Figure 2 depicts the formal, co-taught courses offered over the course of 2018-2019 academic year. Each node in the figure represents a faculty member in the College of Engineering, and the ties represent course sections in which the two faculty were both instructors of during a given semester. The Civil and Environmental Engineering (CEE) and Biological Systems Engineering (BSE) departments had the highest percentage of faculty involved in co-taught courses, at 98% and 89% respectively. One noteworthy point is that the vast majority of co-taught courses in CEE were lab courses, with one affiliated faculty member acting as the primary faculty for all lab courses, while in contrast a majority of the co-taught BSE courses were more traditional lecture courses. On the other end of the spectrum, the Construction Engineering and Management (CEM) Department seemingly offered no co-taught courses and Industrial Systems Engineering (ISE) and Mining and Minerals Engineering (MME) did not fare much better with 1 and 2 faculty from each department, respectively, involved. As a whole, 161 faculty, or around 30% of the faculty in the College of Engineering, were listed as having been involved in teaching a co-taught course in the 2018-19 academic year.

Qualitative Findings

The exploratory findings obtained from faculty involved in co-taught and cross-listed courses are described in this section. Of the four faculty members who were interviewed, one faculty is in the College of Natural Resources and Environment (CNRE) and the other three are in the College of Engineering (COE).

Course Creation through Informal Faculty Networks

In the forestry course example in the CNRE, the faculty member was an associate professor who spoke of her past projects in which she has cultivated working relationships with faculty across the university, particularly in civil and biosystems engineering. One of the courses detailed in the interviews was one that was cross-listed across five departments across three colleges, which was largely due to her large network. She has since left the university, which sometimes can result in a nontraditional course like the one discussed being discontinued, but due to a strong network of collaborators, the course continues to exist.

In another example, a professor with industry experience and a research focus on industry created a course in 2009 with two other professors at different universities "*that he happened to know.*" This course was taught synchronously through online learning management system (LMS) software. After this professor created the course, he moved to a different institution and brought in another professor to continue the course in the department where the course was started, thereby "*teaching the course across four institutions.*" The existing relationships enabled and even inspired these faculty members to create and co-teach courses.

Industry and Discipline-Driven Course Creation

In the forestry course example, the interviewee gave industry needs as a reason for creating the course. She spoke of "*the need for students in forestry to have opportunities to engage with students from other disciplines*" as this will be representative of the work that will be "*required of them in industry.*" Moreover, in a changing university context, this course was able to fit a different set of requirements that is more supportive of interdisciplinarity in the course objectives.

In the synchronous course example, the original professor relied on his knowledge of industry needs to justify the course. According to the interviewee, their engineering discipline is heavily influenced by the trends in industry needs. As industry shifted their values more toward incorporating social context into the engineering curriculum, the department's curriculum also began to value this change. Additionally, this "*department is small in relation to the other engineering departments"* at the university*."* Similarly, the "*disciplinary field is also small"* in relation to others in the domain of engineering. To this effect, the participant noted that there is a notable push for "*research to include education"* outcomes. This discipline-specific culture lends itself to collaborative courses taught by faculty who bring in different perspectives.

In another course example, the faculty member spoke of creating a co-taught, cross-listed course as a way to fulfill curriculum needs for three departments. By co-listing and rotating teaching responsibilities among the three faculty, the departments save resources on teaching while also engaging their students with peers outside of their major. The course has been implemented for nearly ten years, yet each year additional content is incorporated into the course due to individual department demands. Noting this trend, the interview participant expressed that the current curriculum expansion is unsustainable and will either result in the course being "*taught by individual departments or [the instructors] will need to reevaluate the entire course*" to readjust the variety of content delivered in the course.

Additionally, one of the departments is a part of a cross-institutional degree program in that their courses must be taught via distance learning technologies. This "*requirement of [one] department is difficult to impose on [the faculty] from other departments*" and was expressed by the interviewee as another potential reason for the course to become individually taught by the departments. In the original course development process, the three departments were strategic in their support of the course due to less resource demand. However, as the departments develop differently based on external and internal influences, the alignment of their needs also change.

Adapting Courses to Institutional Initiatives

The cross-listed forestry course was also positioned to fit into the recently revised general education curriculum. The faculty member was able to use the institutional expertise of those involved in course approval rather than having to pave a new path. The interviewee noted that the course has yet to be offered to students because it has just recently been passed through institutional measures of course approval. The faculty participant stated that the informal course ideation and subsequent approval was a much longer process that was built on her many faculty relations that developed over her many years of interdisciplinary project collaboration at the university.

Another interviewee spoke of revising an existing course to fit in with university initiatives. In part, the course has been revised to fit into one of the complex problem areas defined by the university. Additionally, it has also included criteria to fit into the new general education infrastructure that is being implemented. The interviewee notes that the reason the instructors requested that the course become a part of one such complex problem area is "*to build more connections between their department with other departments and the university.*" According to figure 1, this department exhibits few connections with other engineering departments. Thus through the top-down institutional influence, this department has used this course to not only offer a multidisciplinary environment for students but to also to bridge their faculty with those outside of the department.

Institutional Supports and Barriers

In the original teaching model for the synchronous course, the lead faculty member leads lectures and discussions, with occasional input from other co-instructors. The lead faculty for the course rotates every semester. This was to save time but still incorporate different perspectives. Additionally, as technology improved, the barriers to synchronous teaching were reduced.

As the course has evolved, the department has partnered with different institutions. Since 2013, the current three co-instructors have used the synchronous teaching model, in which the instructors take on more equal co-teaching responsibilities. In the current division, the instructors have different disciplinary backgrounds, engineering, social science, and small-scale, practice-driven engineering. These differences "*provide different perspectives*" for the course content, as well as bring in "*students with different disciplinary backgrounds and geographic locations*." The cross-institutional collaboration of the instructor team is also achieved with the students, in which they work on "*cross-institutional teams to complete the course projects*." The interviewee also noted that the recent technological change has alleviated many of the distance learning issues that occurred in the past and has "*improved their ability to co-teach*". The software acquisition from an institutional perspective was noted as a "*beneficial resource*" in maintaining and improving the synchronous teaching model.

Discussion

This paper presents two related but distinct social networks among the faculty in the college of engineering. The first is outlined by formal university positions and affiliations and the second by cross-listed and co-taught courses. In the following sections, the discussion is organized by each research question.

1. What are the formal institutional ties between faculty across departments?

From the analysis of formal departmental listings in the College of Engineering, it was found that every department was unique. Departments ranged in size, spanning from 12 to 116 affiliated faculty members. The number of faculty affiliated with other departments also varied, from the completely isolated BSE department to the gregarious ME department, which boasted formal departmental connections with six other engineering departments, over half the college. The size and interconnectedness of departments stem from a variety of mechanisms. One possible explanation for the large variations across departments could be the historical context of when and why each department was established. As a land grant university, this Southeast R1 University has maintained a Mechanical Engineering department in some sense since its inception which remains one of its largest departments to date. In the 1940s, engineering departments saw a large increase in federal grant money following Sputnik and World War II, especially to aerospace and electrical engineering departments [30], which are departments that remain the largest and most connected at Southeast R1 University.

2. How do the formal institutional ties compare to the development of co-taught courses?

Faculty may affiliate themselves with multiple departments for a plethora of reasons. They might have research interests that span departmental boundaries. They may be teaching a course with roots in their home discipline. They may also have obligations to both if their salary is financially supported by both departments. However, at R1 research universities, much like Southeast R1 University, for every reason to collaborate and teach across disciplines, there is a barrier that prevents collaboration. University reward structures for reaching tenure often do not include a teaching component, instead focusing on graduate students, grant money and papers published. Faculty are also not incentivized to experiment with teaching strategies, such as co-teaching, due to a rigid undergraduate curriculum and stringent ABET requirements. Additionally, the differing requirements of accreditation and coursework across departments serve as an additional barrier to faculty in engaging with multidisciplinary courses.

3. How do faculty experience teaching multidisciplinary, co-taught courses?

One of the insights gathered through the qualitative data collection were the assumptions of what the formal data regarding co-taught courses implied. In some instances, courses listed with multiple instructors included lab instructors who were involved with courses that require laboratory facilities. In others, instructors would rotate teaching the course each semester. In this format, the entire course was taught by one instructor at a time and the instructor team would meet a few times a semester to discuss potential changes for the future offering. Lastly, in the interviews, there were mentions of other co-taught, interdepartmental courses that were listed as separate courses in multiple departments with multiple instructors. These courses were, in fact, co-taught courses in which faculty instructors were able to obtain full teaching credit hours. Even though the formal connections outlined by institutional data imply that the courses listed with multiple instructors are co-taught, the variation among how these courses are implemented is known only as corporate knowledge by faculty involved in the courses. From a student perspective, these informational expectations can be difficult to navigate as it shows how formal communication lines may not be as reliable in choosing courses.

In the qualitative exploration regarding four of the courses outlined by the formal data collection, there was a range of types of multidisciplinary courses. One course was born out of an industry need, created through a network of multidisciplinary faculty with existing rapport and good working relationships. Another had been taught in one department for upwards of ten years and, through a new university initiative, decided to revise the content such that the course could be a way to engage the department with partners across the university. The third course was a multidisciplinary course, co-taught across different departments at different institutions. The final course was one that was created to fulfill a curricular need of three departments in the same college. These differences were not at all visible in the formal data that is publically available.

Since the institutional structures across the college of engineering are largely the same in regards to course development, the variety of types of courses in a sample of four was surprising. In the case of the synchronously taught course, the common issue of dividing teaching credit among the co-teachers became a non-issue. Because these instructors taught across departments at different institutions, their individual institutional structures did not affect one another. They used the university-supplied resource of broadcasting software to have the benefit of bringing in different disciplinary perspectives from co-teachers and students without the indirect punishment of reduced teaching credit load as is the case for many co-teaching examples [7], [12], [13].

In contrast, for the cross-listed, co-taught course that was created to fulfill three departmental curricular needs, the interviewee expressed that their teaching team would rotate teaching responsibilities to ensure that whoever was teaching would receive full departmental teaching credit. In this teaching model, a different faculty member would take lead on the course but have regular meetings with the other two faculty members to discuss the course's progress and develop changes for the subsequent offering. The course was never taught by more than one faculty member at the same time.

When the needs of departments align, a strategic co-teaching model is possible but it is difficult to expect this system to be sustainable without a periodic reevaluation of departmental needs. When a course is designed to fulfill multiple departmental needs, the department-specific changes over time will change in different ways due to differences in internal and external influences. The fourth interview example, in which the course was created to fulfill curriculum needs for three departments illustrates that the strategic justification for co-teaching and cross-listing the course requires a process of ongoing readjustment. As departments change individually and have to fulfill different needs, the cost-effectiveness of co-teaching and co-listing the course will go down. The interviewee maintains that this would be a disadvantage for the students who also are given one of few opportunities to collaborate across disciplines with the course.

Limitations

While this paper looks to explore both macro and micro-levels of understanding how multidisciplinary courses form, we acknowledge that our findings are limited to one institution, one database, and a small sample of interview participants. The networks of formal institutional affiliations and listed co-taught courses may not be completed due to how variations in how departments report co-taught courses. Institutional data might depict a course as alternating between two faculty, while in reality, it may be co-taught every semester. Additionally, due to institutional barriers in multidisciplinary course approval, faculty may alternate who the listed instructor is for a given course, even if both take on an active role in teaching. There are many other methods in which faculty engage in interdisciplinary thinking and interactions that have not been discussed here. Faculty committees and co-authored research are two interactions that faculty may have with those outside of their field that may lead to more informal connections.

Conclusion and Future Work

Overall, this work seeks to shed light on some processes by which multidisciplinary courses are established in the college of engineering. Through the use of formal networks highlighting department affiliation and co-teaching lense, we may identify structural barriers that exist at a macro-level throughout the college. In a qualitative exploration of a sample of the courses, we determine that faculty navigate institutional structures differently to create entirely different courses. In one example, faculty changed existing courses to better fit in with institutional initiatives of interdisciplinarity. In another example, faculty used co-listing and co-teaching strategically to fulfill curricular needs for multiple departments. In the third example, faculty co-taught a course with departments at different institutions, of which the process had fewer institutional barriers to navigate. Finally, a course was created because of an industry need for graduates to have interdisciplinary skills. The amount of variance in the types of courses are a point to continue the research. For future work, we will expand the qualitative inquiry by examining a greater number of co-taught and cross-listed courses. Additionally, we seek to detail elements of the university system related to course development, by examining the institutional structures from a lens other than faculty to further understand systems of change in the multidisciplinary engineering courses.

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