Influences on Engineering Instructors' Emphasis on Interdisciplinarity in Undergraduate Courses

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Introduction

Solving many of today's technological and social challenges will require interdisciplinary thought and action[1-5], and the growth of interdisciplinary engineering programs[6] suggests that the field is acknowledging its role in preparing students to tackle complex problems and develop innovations that will advance quality of life, economic growth, and national security. Efforts to enhance students' interdisciplinary knowledge and skills include the development of interdisciplinary design courses through the NSF-funded SUCCEED Coalition and ABET's later accreditation mandate for undergraduate programs to prepare new engineers to work on multidisciplinary teams[7]. Borrego, Froyd and Hall observed that the high level of awareness among engineering department chairs of interdisciplinary capstone design projects was "an obvious response to ABET EC2000 criteria"[8] (p. 197).

Richter and Paretti[9] provided further evidence of the burgeoning interest in interdisciplinary learning experiences through a review of engineering journals and conference proceedings that identified more than 1,500 articles on interdisciplinary courses and projects published in an 8-year time-period. During this same period, two reports on engineering education—*The Engineer of 2020* sponsored by the National Academy of Engineering[10] and *Creating a Culture for Scholarly and Systematic Innovation in Engineering Education*[11] published by American Society for Engineering Education—placed the responsibility and challenge of promoting the development of future engineers' interdisciplinary habits of mind on engineering faculty.

In this study, we ask "What influences engineering faculty members' inclusion of interdisciplinary content and skill development in their undergraduate courses?" Our findings contribute to the emerging literature on interdisciplinary education in engineering, but are also designed to inform a subsequent phase of our analysis, in which we will examine how the factors identified in this study shape the educational experiences of undergraduate engineering students, and, ultimately, students' development of interdisciplinary competence. To ground this work, we first discuss the definitional challenges that arise when studying interdisciplinary education and then review the small body of research on faculty course planning in higher education.

A Review of Relevant Literature

Although there is a vast literature on interdisciplinarity [12], empirical study of interdisciplinary education has lagged behind[13,14]. Engineering education researchers are among the few who are systematically examining the conduct and impact of interdisciplinary courses and programs[15-20]. Most of this research, however, has focused on the experiences of students in interdisciplinary teams[16-25] or interdisciplinary programs[26,27]. Only a few studies have considered the role of engineering faculty in designing these educational experiences[28,29].

A review of the empirical, policy, and descriptives literatures on interdisciplinarity reveals a host of terms coined to describe the goal or act of connecting knowledge from more than one discipline, whether in teaching or research: interdisciplinarity, multidisciplinarity, crossdisciplinarity, transdisciplinarity, to name a few. Scholars who study interdisciplinarity generally distinguish between multidisciplinarity and interdisciplinarity. Typically, the term multidisciplinarity refer to efforts that bring together the perspectives, tools, or insights of two or more disciplines to explain a phenomenon or solve a problem without integrating these disciplinary components into a cohesive whole. Interdisciplinarity, in contrast, refers to research or educational efforts that integrate disciplinary contributions and thus obscure the separate contributions of individual disciplines (for extended discussions, see Klein[30] and Lattuca[31].

Researchers, however, have observed that terms that are distinguished by theorists and scholars are used interchangeably by faculty[32-37]. To capture this variation in our study, we defined interdisciplinarity broadly to include curricular topics that require contributions from multiple disciplines, whether or not faculty seek to integrate disciplinary knowledge or insights.

Influences on Faculty Members' Curricular Decisions

In a multi-institution, multi-field study of faculty course planning, Stark, Lowther, Bentley, Ryan, Martens, Genthon & others[38] found that an overwhelming majority of faculty identified their own background, scholarly training, teaching experiences, and their beliefs about the purposes of education as significant influences on their course planning. When surveyed about their initial steps in course planning, faculty in 10 fields of study reported that they first chose course content and then drew on their own background and characteristics in making curricular decisions. These same faculty also identified a number of campus-level influences that affected their course planning, including program goals, campus facilities, and student characteristics.

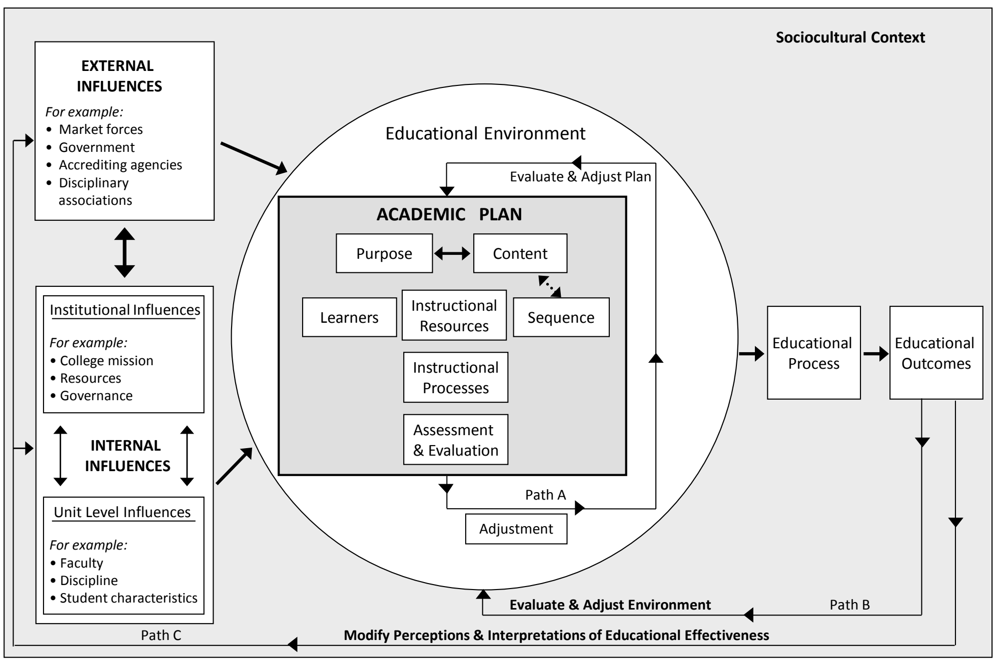
A significant body of research indicates that disciplinary affiliation and socialization are particularly strong influences on faculty as they plan courses. In their studies of faculty across academic fields, Smart and Ethington[39] and Stark et al.[40] each found that disciplinary affiliation influenced the level of importance faculty members assigned to different educational goals. Disciplinary norms can also influence instructional approaches; studies indicate that faculty in scientific, technical, and highly quantitative disciplines generally report using teacher-focused approaches (such as lectures), while those in humanities and social science fields tend to use student-centered pedagogies (such as whole and small group discussions)[41,42]. A recent qualitative study of math and science faculty teaching in three research universities revealed discipline-specific configurations in frequently used teaching methods, cognitive engagements, and the use of instructional technology[43]. One study of more than 1,200 faculty in six engineering subfields revealed subfield variations in faculty members' emphasis on particular curricular topics and instructional methods [44], suggesting that aggregating faculty into broad disciplinary categories (e.g., engineering) may obscure important differences associated with subfield affiliation (e.g., computer engineering, industrial engineering).

Research further reveals that gender and race/ethnicity play a role in instructional choices. Studies consistently show that young faculty, women, and faculty of color are much more likely to use student-centered and active learning instructional techniques than their white and male counterparts[45].

Conceptual Framework

Our goal is to understand the influences that encourage engineering faculty members to emphasize interdisciplinary knowledge, topics, and skills. Our conceptual framing is based on the assumptions of the academic plan model, which posits that a variety of factors, both internal and external to faculty and their institutions, influence faculty as they plan and design courses [46]. The academic plan model (Figure 1) builds on the observation by Toombs and Tierney[47] that a curriculum is "an intentional design for learning negotiated by faculty in light of their specialized knowledge and in the context of social expectations and students' needs" (p. 183). Toombs and Tierney identified three essential parts of a curriculum design process: the "content" that is to be taught; the "context" in which the curricular design is developed; and the "form" that results from the design decisions made.

Figure 1: Academic Plan in Context[46]



The academic plan model is also informed by two studies[48, 49] that clarified the components that Toombs and Tierney identified. These studies defined the *content* dimension as including those things that faculty members bring to the table when they plan a course: their background characteristics and experiences, their views of their academic field, and their beliefs about the purposes of education. These experiences and beliefs inform one another but also shape faculty members' perceptions of the institutional environment—or the *context*—in which they plan courses. Stark et al.[49] identified the *form* of the course as consisting of decisions about course content, curricular sequence, instructional methods, and assessments.

The academic plan model builds on these foundational works in an expanded conceptualization of factors, both internal and external to faculty and institutions, which shape course and program curricula. The model is heuristic in nature; rather than specifying a set of factors that will operate in all postsecondary settings and circumstances, it provides examples of relevant factors (in each of the boxed elements in Figure 1) to alert researchers to the kinds of influences that might be salient for the faculty and curriculum under study.

In this study, we focus on the "unit level" influences that are part of the "internal influences" that affect educational environments and academic plans. The model suggests three key examples of unit-level influences on course and program curricula. In addition to student characteristics, the model identifies faculty members' personal characteristics and their disciplinary affiliations as factors that shape curricular decisions. Since the academic plan model explains curriculum development at the course, program, and institutional levels, it locates disciplinary influences at the unit level, implying that these are not simply present in individual faculty but also collectively as faculty make decisions about their program curriculums. Our focus in this study, however, is at the course level, and we thus examine the characteristics and disciplinary affiliations of individual faculty members.

We focus specifically on faculty members' personal characteristics (such as gender and rank), teaching and industry experiences, disciplinary training, and beliefs about education, all of which have been shown in previous research to influence course planning decisions. In a subsequent analysis, we will examine the influences identified as significantly related to faculty members' emphasis on interdisciplinarity in their courses (i.e., the findings of this study) alongside "external" and "institution level" influences that are also potential curricular influences to provide a fuller picture of the factors related to faculty members' decisions to emphasize interdisciplinarity in their undergraduate courses.

Methods

Design, Population, and Sample

Our analysis draws on a nationally representative data set of 31 four year institutions that allowed us to examine the extent to which engineering faculty members emphasized interdisciplinary skills and content in undergraduate courses (see Table 1). Data were collected from engineering students, faculty, administrators, and alumni as part of a larger study sponsored by the National Science Foundation that focused on the organizational conditions, policies and practices, and student experiences supporting the development of a variety of student learning outcomes. The sample was drawn using the following strata: six engineering disciplines (biomedical/bioengineering, chemical, civil, electrical, industrial, and mechanical), three levels of highest degree offered (bachelor's, master's, and doctorate), and two levels of institutional control (public and private).

Our sample design resulted in a distribution of institutions that are representative of the engineering education population with respect to type, mission, and highest degree offered. Five institutions were purposefully included because they were case study sites in a companion qualitative study. Because one of these institutions only offers general engineering, we also selected three institutions that offered general engineering degrees for comparison purposes. The remaining institutions were chosen randomly.

Table 1. Institutional sample

Research Institutions:	Master's/Special Institutions:
Arizona State University (Main & Polytechnic)[a]	California Polytechnic State University[c]
Brigham Young University	California State University, Long Beach[c]
Case Western Reserve University	Manhattan College
Colorado School of Mines	Mercer University
Dartmouth College	Rose-Hulman Institute of Technology
Johns Hopkins University	University of South Alabama
Massachusetts Institute of Technology[a]	
Morgan State University[b]	
New Jersey Institute of Technology	**Baccalaureate Institutions:**
North Carolina A&T[b]	Harvey Mudd College[a]
Purdue University	Lafayette College
Stony Brook University	Milwaukee School of Engineering
University of Illinois at Urbana-Champaign	Ohio Northern University
University of Michigan[a]	Penn State Erie, The Behrend College
University of New Mexico[c]	West Virginia University Institute of Technology
University of Texas, El Paso[c]	
University of Toledo	
Virginia Polytechnic Institute and State University[a]	

[a] Institution participating in the companion qualitative study
[b] Historically Black College or University
[c] Hispanic-Serving Institution

A university survey research center collected data through a web-based questionnaire. Out of the 2,942 surveys sent out, we received usable responses from 1,119 faculty members for a response rate of 38%. Of those, 987 were from tenure-track or tenured faculty, on which we report in this study. These faculty members typically engage in different professional development opportunities and have different reward structures and criteria than their tenured and tenure-track colleagues[50]. We did not have population-level data that separated out non-tenure track instructors, so we are unable to report a response rate for faculty by their appointment status.

Descriptive statistics of the unweighted sample are shown in Table 2. Like engineering faculty across the nation, males dominated our sample (86%). The majority of respondents were White Americans, 4% self-identified as members of underrepresented minority groups (i.e., African Americans, Hispanic/Latino/a Americans, and Native Americans), and nearly a third of the sample are included in an "other" race/ethnicity category that includes foreign national and naturalized U.S. citizens, faculty members who listed multiple race/ethnicities, and categories of race/ethnicities that were too small to report on their own (e.g., Middle Eastern). Table 2 also reports descriptive statistics for faculty members' rank and home departments. For multivariate analyses, we adjusted the data so that our sample was representative of the population of engineering faculty members at the institutions participating in the study.

In addition, Table 2 includes information on the types of courses that faculty responding to the survey taught "regularly." The vast majority (90%) reported on a fundamental math or science course or a required or elective engineering course; 10% reported on a first-year or capstone design course. Faculty also reported on number of years of experience they had teaching and working in industry. On average, faculty in our sample taught for more than 17 years, which corroborates their responses to the faculty rank question, as nearly half of the respondents were full professors. Our sample had considerably less experience working in industry, working on average less than four years either before or during their faculty career (e.g., as a consultant).

Variables and Analyses

We imputed missing data based on procedures recommended by Dempster, Laird, and Rubin[51] and Graham[52] using the Expectation-Maximization (EM) algorithm of the Statistical Package for the Social Sciences (SPSS) software (v.18). To reduce data from several survey questions into fewer scales, a principal axis analysis (Oblimin with Kaiser Normalization rotation) was completed. Items were assigned to a scale based on the magnitude of the factor loading, the effect of including an item on the scale's internal consistency reliability, and according to professional judgment. Scales were formed by taking the sum of respondents' scores on the items on a factor and dividing by the number of items in the scale as prescribed by Armor[53].

The dependent variable is the extent to which faculty members emphasize interdisciplinarity in a course that they regularly teach (Table 3). This scale was constructed following factor analysis of several program emphases items in the survey. With a Cronbach's alpha of .86, the scale is characterized by a strong internal consistency.

Table 2. Unweighted descriptive statistics of faculty respondents (N=987)[1].

Variable	Mean/Proportion
Gender	86% male 14% female
Race/Ethnicity	55% white 9% Asian American 4% underrepresented minority[2] 32% other[3]
Engineering department	6% biomedical/bioengineering 11% chemical 17% civil 45% electrical 7% industrial 7% mechanical 20% other
Faculty rank	48% full professor 27% associate professor 25% assistant professor
Type of course taught most often	90% teach fundamental science or math course, or required or elective engineering course 10% teach first-year or capstone design course
Years teaching at the college level	17.2 years (standard deviation: 12.1 years)
Years in industry while faculty	3.6 years (standard deviation: 6.3 years)
Years in industry before faculty	3.7 years (standard deviation: 4.8 years)

[1] Percentages are rounded to the nearest integer, so sums may not equal 100%.
[2] Includes African American, Hispanic or Latino/a, and Native American.
[3] Includes Other, multi-racial, naturalized U.S. citizen, foreign national

Table 3. Dependent variable scale with item components. The Cronbach's *alpha* indicates the internal consistency reliability.

DEPENDENT VARIABLE:

Interdisciplinarity course emphasis (alpha=.86; mean=3.01; std. dev.=.97)

Question Stem: In this course[1], how much do you emphasize?[2]

- Making explicit connections to knowledge and skills from other fields.
- Integrating knowledge from engineering and other fields to solve engineering problems.
- Applying knowledge from other fields to solve an engineering problem.
- Understanding how an engineering solution can shape/be shaped by environmental, social, cultural, political, legal, economic, and other considerations.
- Understanding how non-engineering fields can help solve engineering problems.

[1] Faculty members were asked to report about an undergraduate course that they regularly teach.
[2] 1=Little/no emphasis, 2=Slight, 3=Moderate, 4=Strong, 5=Very strong

The goal of this study is to determine how that emphasis varies as faculty members espouse different views of undergraduate engineering education broadly, the role of the engineering curriculum more specifically, and their responsibilities as a teacher even more specifically (i.e., the independent variables, see Table 4). We selected items for this analysis that theoretically could be linked to their views on interdisciplinarity (and in turn the topics emphasized in their courses). Blocked multiple linear regression analyses link our group of control variables and independent variables to the interdisciplinarity course emphasis dependent variable.

Table 4. Descriptive statistics of independent variable survey items.[1] Means are shown for each variable with standard deviations in parentheses.

INDEPENDENT VARIABLES	
Stem: To what extent do you agree or disagree with the following statements about <u>undergraduate engineering education</u>?	
Humanities and social science courses are important in preparing engineers	3.78 (.89)
Interdisciplinary learning should be part of the engineering curriculum	3.84 (.79)
The engineering workplace requires systems thinking	4.24 (.64)
Concepts of sustainability should be a major focus of the undergraduate curriculum.	3.39 (.95)
Stem: To what extent do you agree or disagree that the <u>engineering curriculum</u> should:	
Teach students about intercultural communication	3.22 (.94)
Teach students to consider all relevant factors (e.g., social, cultural, environmental) in designing solutions	3.94 (.73)
Prepare students to assume community leadership roles	3.47 (.87)
Prepare students to work effectively across national and cultural boundaries	3.77 (.80)
Develop students who can think like entrepreneurs	3.49 (.85)

Provide opportunities for students to prepare for occupations other than engineering (e.g., business, medicine, law)	3.34 (.84)
Stem: Do you agree or disagree that as a teacher, it's your responsibility to:	
Ask students to make connections across engineering disciplines	3.94 (.74)
Help students consider the world from multiple perspectives	3.80 (.84)
Prepare students for the role of citizen	3.52 (.87)
Understand the value of diversity in its many forms (e.g., ideas, cultures, gender)	3.41 (.95)
Help students understand the value of a liberal education	3.33 (.91)

[1] Scale, where 1=Strongly disagree, 2=Disagree, 3=Neither agree nor disagree, 4=Agree, 5=Strongly agree

Results

Overall, faculty respondents reported a moderate degree of emphasis on interdisciplinarity (Table 3). Our survey noted that recent reports have discussed the changing knowledge and skills engineers will need in the future and how engineering education needs to change. When asked to what extent they agree or disagree with statements about undergraduate engineering education, faculty agreed most strongly that the engineering workplace requires systems thinking (see Table 4). They also agreed—though not as strongly—that humanities and social science courses were important for preparing engineers and that interdisciplinary learning should be included in the engineering curriculum. Though still in agreement, they were also less enthusiastic about including sustainability as a major concept in the undergraduate curriculum.

When asked about what should be included in the engineering curriculum, respondents were in strongest agreement that the undergraduate curriculum should teach students to consider a variety of factors in designing solutions and preparing students to work effectively across national and cultural boundaries (see Table 4). They were least supportive of teaching intercultural communication skills and only slightly more supportive of providing students with opportunities to prepare for occupations other than engineering (e.g., business, medicine, law). Finally, when asked about their responsibilities as a teacher, faculty respondents agreed that it was their responsibility to ask students to make connections across the engineering disciplines but were less supportive of statements asserting that they should prepare students to be citizens, understand diversity in its variety of forms, and help students understand the value of a liberal education.

The regression analysis in Model 1 linked the control variables to the interdisciplinarity course emphasis dependent variable (see Table 5). This model explained 10% of the variance in interdisciplinarity course emphasis, with the r-squared value adjusted for the number of variables. The faculty member's discipline was a significant positive predictor of interdisciplinary course emphasis, with faculty members with appointments in biomedical/bioengineering, civil, industrial, and "other" (i.e., a discipline other than the 7 engineering disciplines included the study) engineering disciplines reporting higher emphases on interdisciplinarity than the reference group of electrical engineers. We also ran analysis of variance with a Bonferroni posthoc analysis (p<.01) to compare each of the disciplines (i.e., all

Table 5. Multiple linear regression results, where the dependent variable is course emphasis on interdisciplinarity. Standardized coefficients allow direct comparison between variables with different units of measurement.

VARIABLES	Model 1: Controls	Model 2: Controls + Independent Variables
CONTROLS		
Gender (ref=male)	.04	.00
Asian American (ref=White)	.07	.06
Underrepresented Minority (ref=White)	.05	.03
Other race (ref=White)	.07	.07
Biomedical/bioengineering (ref=electrical)	.11*	.08*
Chemical engineering (ref=electrical)	.05	.04
Civil engineering (ref=electrical)	.15*	.07
General engineering (ref=electrical)	.02	-.02
Industrial engineering (ref=electrical)	.12*	.08*
Mechanical Engineering (ref=electrical)	.07	.08*
Other discipline (ref=electrical)	.09*	.06
Faculty rank	.05	.00
Course type: design (ref=All others)	.21*	.15*
Years teaching at the college level	-.07	-.03
Years in industry while faculty	.12*	.11*
Years in industry before faculty	-.04	-.02
INDEPENDENT VARIABLES		
Statements about Undergraduate Education:		
Humanities/social sci courses are important in preparing engineers		.05
Interdisciplinary learning should be part of the eng curriculum		.08*
The engineering workplace requires systems thinking		-.01
Concepts of sustainability should be a major focus of the undergrad curric		.14*
Engineering Curriculum Should:		
Teach students about intercultural communication		-.08
Teach students to consider all relevant factors (e.g., social, cultural, environmental) in designing solutions		-.01
Prepare students to assume community leadership roles		.07
Prepare students to work effectively across national and cultural boundaries		.00
Develop students who can think like entrepreneurs		.02
Provide opportunities for students to prepare for occupations other than engineering (e.g., business, medicine, law)		-.05
Responsibility as Teacher:		
Ask students to make connections across engineering disciplines		.14*
Help students consider the world from multiple perspectives		.12*
Prepare students for the role of citizen		.03
Understand the value of diversity in its many forms (e.g., ideas, cultures, gender)		.16*
Help students understand the value of a liberal education		-.04
ADJUSTED R-SQUARED	0.10	0.26

* Denotes statistical significance (*p*<.01)

related to their emphasis on interdisciplinarity: 1) interdisciplinary learning should be a part of the engineering curriculum, and 2) concepts of sustainability should be a major focus on the undergraduate curriculum. None of the faculty members' views of the engineering curriculum significantly related to their emphasis on interdisciplinarity in their courses. Though not significant, two of these variables negatively related to interdisciplinarity: 1) teach students about intercultural communication, and 2) provide opportunities for students to prepare for other occupations other than engineering. These findings may provide insight on how faculty members perceive interdisciplinarity and the types of skills or outcomes that they do and do not consider to be related to interdisciplinarity.

In contrast, we found significant relationships for items that specifically asked faculty members to report on their responsibilities as a teacher. Believing that it is one's responsibility to make connections across engineering disciplines, to help students consider the world from multiple perspectives, and to help students understand the value of diversity in its many forms are positively related to an emphasis on interdisciplinarity. We did not, however, find a relationship for two teaching responsibility statements: 1) preparing students for their role as a citizen and 2) helping students understand the value of a liberal education. Again such findings may suggest the kinds of responsibilities that engineering faculty view as falling outside their purview and thus which do not influence how they structure their courses.

Discussion

Our goal in this study was to understand the personal characteristics and beliefs that are associated with faculty members' emphasis on interdisciplinary topics in their undergraduate engineering courses. The conceptual framework that shaped the study posits that a variety of factors interact to influence how individual faculty plan and teach their courses. These include the individual characteristics we examined in this study, as well as factors such as department and institutional culture and organizational features of the institution. Our findings speak not only the research question we have asked but to the question of how engineering programs might include more interdisciplinary topics and opportunities for interdisciplinary thinking in their courses.

Overall, engineering faculty reported a moderate emphasis on interdisciplinarity, and a number of variables are positively associated with this emphasis (after taking into account a number of control variables, including gender, race/ethnicity, rank, and teaching and industry experiences). Among the personal characteristics that remain significant in the full model is the faculty member's disciplinary affiliation. An appointment in bio/biomedical engineering, industrial, and mechanical engineering is associated with a greater emphasis on interdisciplinarity in one's courses (relative to electrical engineering). (Departmental appointment and Ph.D. field of study are strongly correlated in our sample.) This finding is consistent with previous research indicating that faculty members' disciplinary socialization is a significant influence on their course planning[54,55]. Bio/biomedical and industrial engineering are often perceived as more interdisciplinary in their approach, and our analysis suggests that this is the case, at least in terms of teaching approaches. In our analysis, however, disciplinary affiliation is one of several influences on interdisciplinary course emphasis in engineering, and not the strongest one.

Having more years of industry experience, gained while a faculty member, is more strongly associated with an emphasis on interdisciplinarity than one's disciplinary appointment. Regardless of one's educational background, industry experience appears to be associated with a greater appreciation of the role of interdisciplinarity in engineering practice and may provide faculty with more ideas about how to draw interdisciplinary connections and illustrations. Previous studies have not typically examined the effects of work experience in curriculum planning, although such experiences are likely to be a salient influence in professional fields like engineering, business, and education that are associated with specific occupational fields and practice communities.

Teaching design courses is even more strongly associated with an emphasis on interdisciplinarity than work experience, and represents one of the strongest relationships identified in this analysis. For those who believe more interdisciplinarity rather than less is needed in the engineering curriculum, this finding may be cause for concern since design courses constitute a small proportion of the undergraduate curriculum in many institutions. In our sample, we found that while all participating engineering programs in the seven targeted disciplines required a capstone design course, fewer required first-year design or design courses in the sophomore and junior years of study. In programs that do not ground their curriculum in design learning, faculty will need to think individually, but also collectively, about how to integrate interdisciplinary examples, topics, and skill building into existing courses. A review of the program curriculum, with a focus on identifying interdisciplinary linkages and skill-building opportunities, will enhance efforts to graduate engineers who have the disciplinary depth and interdisciplinary breadth needed for success in an engineering workplace that expects teamwork and collaboration across disciplinary boundaries.

Building on the contextual filters model of course planning, the academic plan model that guided this study assumes that faculty members' views of education shape their decisions about what to include in their courses. We thus examined the relationships between a number of beliefs about education and teaching (that could reasonably be associated with an interdisciplinary outlook) with faculty members' reports of interdisciplinary emphasis in their undergraduate courses. Our findings align with the expectations of the conceptual model.

Unsurprisingly, we found that emphasizing interdisciplinarity in one's courses is associated with the view that interdisciplinary learning should be a part of the engineering curriculum; however, this relationship is modest. The belief that sustainability should be a major focus on the undergraduate curriculum is more strongly related to an emphasis on interdisciplinarity. This latter finding may provide a practical suggestion for increasing attention to interdisciplinarity in courses, and particularly in design courses, since sustainability can be incorporated into the design process via a triple bottom-line consideration.

Believing that it is one's responsibility as a teacher to ask students to make connections across engineering disciplines, and to help them understand the world from multiple perspectives, are also associated with a greater emphasis on interdisciplinarity in one's courses. These two findings are also notable because the standardized coefficients for these variables are more strongly related to interdisciplinary course emphasis than many others in our analysis. Moreover, one of these variables, which measures the strength of the belief that it is one's responsibility to help students understand the value of different kinds of diversity (e.g., ideas, cultures, gender), stands out not only because it is one the strongest relationships identified in our analysis, but because it is also one of the variables with the lowest mean. Faculty who believe it is their responsibility to teach about diversity in terms of race, gender, and culture report making interdisciplinary connections in their courses, but these topics do not appear widespread across the engineering curriculum.

Given the role that faculty members' beliefs play in their decision-making about course content, discussions of underlying rationales for curricular choices might be part of a program's efforts to review its emphasis on interdisciplinarity. Such discussions ask faculty to articulate their reasons for including particular topics in a course and what they hope to achieve as a result. These discussions can be productive because very few engineering faculty come to their academic positions having had formal experiences as graduate students that focused on their roles as instructors[56], and because focused conversations can contribute to the development of a shared vision of an academic program.

We found no significant relationships between interdisciplinarity in course emphasis and the six statements about what the engineering curriculum should do. Although our descriptive statistics indicate that faculty respondents expressed strong support for teaching students to consider social, cultural, environmental and other factors in designing engineering solutions and to prepare students to work effectively across cultural and national borders, the lack of significant relationships in regression results suggest that faculty may not associate these educational goals with the concept of interdisciplinarity. Given the great variety in personal understandings of interdisciplinarity (noted earlier), such an interpretation is plausible. If this is the case, these findings may reflect a semantic distinction that is not of practical importance: students may be learning interdisciplinary ways of thinking and engaging with other disciplines without faculty labelling such engagements as "interdisciplinary." Teaching students to consider all the relevant factors in an engineering understanding or to think like entrepreneurs may be considered central to engineering practice rather than representative of interdisciplinarity.

Finally, the lack of significant relationships between interdisciplinary course emphases and survey statements regarding the role of engineering education in preparing students for their roles as citizens, as leaders in their communities, and about the value of liberal education may suggest that more discussion of the goals of engineering education is also needed. In 1993, Bordogna, Fromm and Ernst[57] argued that:

> The ability to make connections among seemingly disparate discoveries, events, and trends and to integrate them in ways that benefit the world community will be the hallmark of modern leaders. They must be skilled at synthesis as well as analysis, and they must be technologically astute. Within university communities, in particular, we must create an intellectual environment where students can develop an awareness of the impact of emerging technologies, an appreciation of engineering as an integral process of societal change, and an acceptance of responsibility for civilization's progress. (p.4)

These same sentiments are reflected in the National Academy of Engineering's *Engineer of 2020*, which inspired the larger study from which this data is drawn. As we draw closer to 2020, the Academy's concern regarding the readiness of the engineering community to prepare students for their many, intersecting professional and societal responsibilities remains.

The Next Phase of Our Research

The academic plan posits a number of influences on courses and programs in higher education that are not measured in this study. First, the model assumes that external influences can also shape higher education curricula. In engineering, for example, accreditation plays a strong role in shaping the undergraduate curriculum[58]. In many fields including engineering, disciplinary and professional associations seek to shape the views of their members, with some taking strong stances and leadership roles. Organizations such as the National Academy of Engineering, the National Science Foundation, and the American Society for Engineering Education often seek to encourage specific curricular and pedagogical practices[59-61]. Finally, industry advisory boards common in many engineering schools and programs serve as a conduit for employers' views, pressing faculty to ensure their program curricula are relevant to industry needs. We plan to assess these potential influences in the next phase of our analysis.

The academic plan model further posits an array of institutional-level influences, such as institutional missions, financial and human resources, and governance arrangements. These influences can support curriculum, but as is often noted in the research on interdisciplinarity, they can also be impediments to interdisciplinary activity. In the next phase of study, we examine the relative influence of institution-level influences (such as faculty reward systems and institutional missions) and the unit-level influences we have identified in this study to provide a more comprehensive understanding of the factors associated with interdisciplinarity in engineering courses.

Conclusion

Policy discussions of engineering often focus on the need for interdisciplinary approaches to problem-solving and result in calls for greater emphasis on interdisciplinary learning experiences at the graduate and undergraduate levels. This study of faculty in seven engineering disciplines across 30 institutions suggests that faculty support for interdisciplinary education is modest, and appears strongest among faculty who teach design courses, have ongoing relationships with industry, and who believe it is their responsibility to help students make connections, embrace sustainability and diversity, and view the world from multiple perspectives.

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