Investigating Student Motivation and Performance in Electrical Engineering and Its Subdisciplines

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***Abstract*—Factors influencing choice of major in electrical engineering and later curricular and professional choices are investigated. Studies include both quantitative and qualitative analyses via student transcripts, surveys, and focus groups. Student motivation for choosing an electrical engineering major and later subdiscipline in the field is interpreted through expectancy-value theory, where primary factors of strong perceived value of future professional opportunities and strong influence of course instructors are identified. Performances in select required electrical engineering courses appear to serve as predictors for student choice of subdiscipline emphasis. In contrast, participation in student professional activities does not show statistically significant correlations with subdiscipline. Curricular and professional choices appear to be explained by expectancy-value theory with inclusion of socializers. The findings suggest that early and integrative exposure of all electrical engineering technical areas, including high-quality teaching, may provide an optimal basis for students to make future decisions on academic path and participation in professional activities.**

***Index Terms*—Choice of major, expectancy-value theory, social influences, subdiscipline.**

I. INTRODUCTION

ELECTRICAL engineering (EE) is one of the broadest disciplines within engineering, with its subfields of study often being unknown to students in their early undergraduate years. While many students are familiar with electrical power, circuits, and electromagnetics, key areas including signal processing, control systems, optics, and semiconductor devices are often unfamiliar. In addition to academic performance, the student experience extends well beyond the classroom, where engaging in the multitude of research projects, student project teams, and related professional experiences can transform educational outcomes. Identifying factors that correlate with students' motivation to choose EE as a major, their choice of subdiscipline within EE, and their academic performance is invaluable in informing recruiting, advising, mentoring, and curricular reform activities.

Prior studies have examined factors that correlate to choice of major within engineering [1]–[5]. A study drawing from a large multi-institution database concluded that gender and race are important factors [1]. For example, the study found that EE is much more popular with Asian and Black females than Hispanic and White females, recommending further study to understand the reasons behind the enrollment and graduation statistics. Differences in gender and parental educational achievement were cited as contributing factors for choice of engineering major at the University of New Haven, West Haven, CT, USA, recommending further inclusion of qualitative data and larger sample size [2]. Another analysis of a national multi-institutional survey indicated that the level of motivation for students of different engineering majors may vary with gender, but that the variation is not significant for EE [3]. Factors determining choice of an engineering major have been studied previously [4], where a qualitative study based on expectancy-value theory emphasized the importance of understanding values and connecting personal identities to engineering identities. The diversity of technical fields within engineering, and subdisciplines within a particular engineering major, however, may attract student populations with differing values and identities.

The diversity of technical areas within EE may incite varied motivations, attitudes, and expectations among students; gaining an understanding of these facets may be used to guide educational reforms. Studies of motivations and attitudes in various engineering majors have been shown to exhibit different expectancies of success for student performance in their major; understanding these differences is believed to help direct instructional change to suit the student population within a given major [5]. Instructional change has also been shown to impact recruiting of mechanical engineering students to pursue a minor in EE at Temple University, Philadelphia, PA, USA[6], where emphasis on pedagogical strategy and motivation were shown to be effective. EE can be considered, and taught, as a set of subdisciplines, but it may ultimately be better to develop a more holistic and interconnected teaching of EE material between subdisciplines. Initiatives at Duke University, Durham, NC, USA, have reported advantages in following this approach [7]. Understanding student motivation and success at the University of Michigan, Ann Arbor, MI, USA, is an important step towards undertaking instructional reform that can better address student needs.

Student motivations to major in EE, and the choices they make during their education, can be interpreted through the lens of expectancy-value theory, including the impact of social influences [8]–[11]. The expectancy-value theory describes decision making as based on the individual's expectancy of success and on the anticipated value of the outcome, which includes negative value (costs) of engaging in the action. With respect to choosing EE as a major, students' perceptions of their ability to graduate in the field, and the value they see in career opportunities in EE, will affect their decisions. These motivations include the influence of social factors on achievement-related motivations and choices [9].

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Ultimately, to support success for students in EE, an understanding is needed of why they enroll in the first place and how they progress through the program. Thus, this work focuses on students' motivations to become an EE, and on how student characteristics and choices correlated to success in an EE program. This project was undertaken in the Department of Electrical Engineering and Computer Science (EECS) at the University of Michigan to understand factors that determine student choices for major, subdiscipline, and participation in professional activities. The information garnered from the study could then be used to target recruiting activities, improve student advising, and motivate future initiatives in the department for curricular reform and extracurricular professional activities. This project examines academic performance and behavior for students in EE, as well as subdiscipline trends within EE. Data are analyzed to study potential dependencies on student performance, choice of classes, involvement in professional activities outside of the classroom, and overall impressions of the undergraduate experience. Historical academic performance data, feedback from focus groups, and survey data from graduating students over the past two years are used to examine motivations for choosing EE and curricular and co-curricular choices in EE.

II. Methods

This study is guided by two research questions : 1) What reasons do students cite for choosing EE as a major?; and 2) How does student performance in EE vary by student demographics and curricular and co-curricular choices? Data from student transcripts, surveys of graduating students, and focus groups of current students are used to address these questions. To provide some context to the population of this study, undergraduate students enroll in the College of Engineering, and later declare their major within engineering, typically in freshman or sophomore year. The College of Engineering is highly selective; students entering in the Fall 2014 semester had a 28% acceptance rate, mean high school grade point average of 3.9, mean ACT score of 33, and mean SAT score of 1430.

Transcript data were analyzed for students graduating with a bachelor's degree in EE between 2005 and 2012. The data included grade performance, gender, and choice of academic courses, and provided information on student performance, demographics, and curricular choices. The data set encompasses 1032 graduates and includes grades for core math, physics, and engineering courses required in EE, as well as the selected senior capstone design courses. Descriptions of the courses are shown in Table I. In the EE program at the University of Michigan, students choose their senior capstone design courses from a set of courses with varying technical emphasis. At least one of the chosen course combinations includes an EE prerequisite elective course. The choice of capstone design course provides an indicator for subdiscipline (though there are no formal declaration requirements). For the purpose of this study, subdisciplines are categorized in the areas of circuits/solid state, electromagnetics/optics, signals and systems, and computers.

TABLE I
List of Courses Examined in the 2005–2012 Data Set Used in This Study

Course	Title	Subdiscipline
Math 215	Calculus III	Required
Math 216	Differential Equations	Required
Physics 240	General Physics II	Required
Engineering 100	Intro. Engineering	Required
EECS 215	Electronic Circuits	Required
IEECS 216	Signals and Systems	Required
EECS 230	Electromagnetics I	Required
EECS 280	Programming	Required
EECS 320	Semiconductor Devices	Required
EECS 401	Probability	Required
EECS 411	Microwave Circuits	Circuits/Solid State
EECS 413	Amplifier Circuits	Circuits/Solid State
EECS 425	Integrated Microsystems	Circuits/Solid State
EECS 427	VLSI Design	Circuits/Solid State
EECS 430	Radiowave Propagation	EM/Optics
EECS 438	Lasers and Optics	EM/Optics
EECS 452	Digital Signal Processing	Signals/Systems
EECS 470	Computer Architecture	Computers

Surveys were constructed to be administered to graduating students to investigate student behavior not available on student transcripts (e.g., participation in professional activities), and to enquire directly about students' motivations for majoring in EE. The survey instrument, based on prior studies of engineering major choice [2] and choice of major in Information Systems [12], was adapted for the academic program at the University of Michigan and posted at [13]. Likert-scale questions used a six-point scale to eliminate the ability to select a neutral response. The survey was offered to students through the EECS undergraduate advising office when they submit paperwork for graduation. The results shown in this study are for students graduating in the 2013–2014 and 2014–2015 academic years (a subset of the pool of students covered by the transcript data described earlier). A total of 163 students (62% of students receiving a bachelor's degree in EE during this timeframe) responded.

Additionally, focus groups were conducted to provide additional qualitative information on how students decide to choose EE as a major and on other choices they make in their academic career. Four focus groups were conducted: for students who had not yet declared a major, for recently declared majors, for juniors, and for seniors who had completed their major design course. Ten randomly chosen students were contacted by e-mail from targeted courses to provide representative data for the intended student categories: ENGR 110 (survey course in engineering for first year students with undecided major), EECS 215, EECS 320, and EECS 496 (required course on engineering professionalism to accompany senior capstone design). The aim was to capture a cross section of students at their first, second, third, and fourth year, regardless of subdiscipline. Students could decline the invitation. Each focus group had between five and eight participants, was conducted by a single researcher, and lasted about an hour. Focus group discussion was audio recorded for further analysis. Students were asked

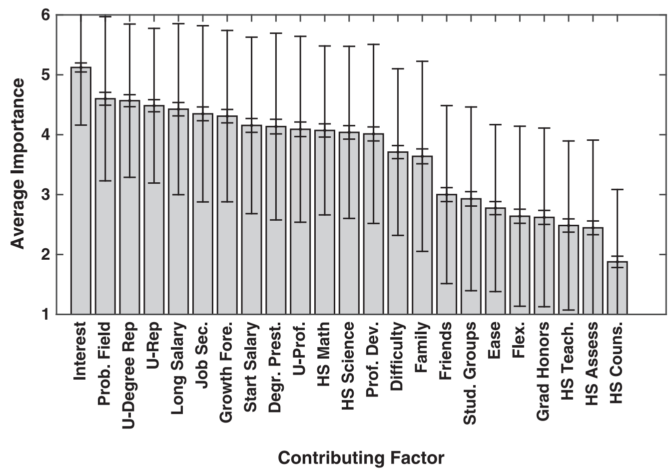

Fig. 1. Ranked average importance for source of influence in decision to choose major in electrical engineering. Values are shown for the mean response in each category, standard deviation (large error bars), and standard deviation on the mean (small error bars). (Prob. Field = probability working in the field after graduation.)

approximately five questions related to their experiences and choices. Sample questions included "How did you choose EE?", "Who or what influenced your decision?", and "How did you choose your senior capstone design course?".

III. Findings

A. Motivations

The decision to choose EE as a major was investigated using data from surveys and focus groups. The average importance of contributing factors to choice of major in EE is shown in Fig. 1 in ranked order. Interest in the technical area of EE, job prospects and related salary, and the prestige of the institution and degree were rated highly as contributing factors to the choice of EE as a major. Influences at the high school level, the perceived easiness of technical field and job flexibility, and influence of family and friends were rated with less emphasis. The survey data suggest that students who eventually choose EE, and are ultimately on the path to graduation, value their technical interests in the field and their career prospects higher than social influences. These motivations for choosing EE as a discipline agree well with expectancy-value theory, where career prospects and inherent technical interest provide the largest combination of expected success and enjoyment (value) for these students. Perhaps not surprisingly, graduating students also reported that they were well informed about the technical field and career prospects in EE prior to declaring, and even more aware of the field of EE than other engineering fields. A comparative survey for students who choose engineering majors in other fields would provide a better understanding of the importance of prior knowledge of a particular engineering discipline as a contributing factor to choice of major.

Focus group responses indicated that students were often inherently interested in the subjects of EE, with their parents playing a role in their understanding of the versatility of the major. For example, one respondent reported, "*My dad did his undergrad in EE. He said if you don't know what to do, try EE. The analytical analysis is good in general*." Parental influence and the importance of general analytical skills in choice of EE major were reported by multiple respondents, which is also consistent with general feedback from EE advisors. This data suggests the impact of socializers on choice of engineering major, consistent with expectancy-value theory with parents acting as a model for their children.

To understand how EE students then choose a specialization within the discipline, feedback was analyzed from focus group discussions. In some instances, students indicated that their experiences in research or at an internship motivated them to enroll in classes associated with their work. Even with nontechnical internships, the introduction to a specific subdiscipline motivated student interest in the field. For example, one student describing experience at a summer internship commented, "*I took power systems because I saw the power team at Northrop Grumman was interested (in the topics covered by the course). I thought if I took a power class, I might be able to work with the power team.*" Furthermore, many students indicated that particular professors or graduate student instructors played significant roles in motivating students' appreciation of a subdiscipline, as evidenced by students subsequently enrolling in classes taught by, or suggested by, the instructors. One early required course, in particular, is taught by two instructors who have different teaching styles. One of these professors has motivated students to pursue the course's subdiscipline, while the other has caused students to not only move away from that subdiscipline, but to even change their major to computer science. Another student describing their choice of EECS 411 as their senior capstone design course reported, "*I wanted to take that after taking 230 with Prof. X. I liked the transmission line stuff. The courses that led up to that were 230, 311 analog circuits (Prof. Y was very good). I really understood those classes well*." While this is data garnered from a small number of students, it illustrates the impact instructor reputation and ability may have on student motivation. Open-form responses on the surveys also suggest that specific instructors were highly influential on student decisions on courses and activities.

The impact individuals can have on student choice of a subdiscipline is illustrated several times by this data, where students are profoundly affected by social interaction with experts in the field. This information suggests that having successful instructors teach introductory courses may lead to higher student motivation and better retention within EE.

The motivations for choosing EE as a major as well as subdiscipline within EE appear to follow expectancy-value theory, with the initial choice of major seeming to be largely dictated by the prospect of future professional opportunities and inherent interest in the field. Students also report that outside influences, including parents and particular course instructors, can strongly influence decisions, suggesting the influence of socializers on expectancy-value and motivating choice of major and subdiscipline in EE.

B. Performance

Student performance was also studied to gain a better understanding of how students succeed in EE. The relationship

TABLE II
ANOVA Analysis to Test Association of GPA With Listed Dependent Variables

Dependent variable	***p*-value**
Gender	.486
Parental Educational Background	.114
Plan to attend grad school in science/engineering	**<.001**
Plan to begin job in engineering	**<.001**
Involvement in student society	.138
Involvement in student project team	.689
Involvement in research	**.005**
Involvement in internship/co-op	.061

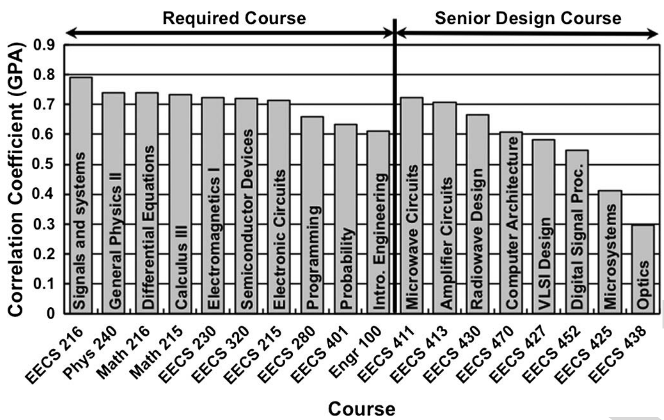

Fig. 2. Correlation coefficient between graduating GPA and grade in selected required courses and senior capstone design course.

between student performance and demographics was examined from the survey data containing mean self-reported grade point average (GPA), gender, parental background, and plans after graduation. Differences between group performance were examined using a t-test statistical analysis, where p-values less than 0.05 suggest statistical significance. The comparative groups and associated p-values are summarized in Table II. The p-value results suggest that there is not a probable correlation of GPA with gender or parental educational background (whether or not a parent has a college degree). However, there is a highly probable correlation of GPA with future plans to attend graduate school and to work in a job in engineering directly following graduation. The survey data suggest that students with high GPA intend to pursue graduate studies in science and engineering, while lower-achieving students plan to begin a job in engineering directly following graduation.

Potential predictors of academic success in EE were studied using student transcript data to determine the degree of correlation between graduating GPA and course grade in early required courses. Correlation coefficients were examined for all required courses in EECS, and a selection of required courses in math, physics, and engineering. A summary of calculated correlation coefficients for courses with respect to graduating GPA is shown in Fig. 2, sorted in descending order and by category of required course or senior capstone design. Strong correlations are observed for required courses, while weaker correlations are observed for the major design capstone courses,

TABLE III
ANOVA Analysis to Test Association of Relative Performance in a Particular Course With Subdiscipline in Electrical Engineering

Course	***p*-value**
Math 215 - Calculus III	.740
Math 216 - Differential Equations	.114
Physics 240 - General Physics II	.675
EECS 215 - Circuits	**.001**
EECS 216 - Signals and Systems	**.002**
EECS 230 - Electromagnetics I	**<.001**
EECS 280 - Programming	**.001**
EECS 320 - Semiconductor Devices	**<.001**
EECS 401 - Probability	**.045**

likely due to relatively high grades for all students in these team design courses. As EECS 215 is the first required course for EE within the major, it is not surprising to see a strong correlation and the probability that the course serves as a predictor of future academic success in the major. In contrast, the EECS 438 course is a senior capstone design course where most students and their groups succeed in their open-ended design challenge, consequently receiving relatively high grades for all students. The EECS 280 course demonstrates a relatively strong correlation, though the average grade is shifted below the one-to-one line, indicating generally lower relative performance or a "grade penalty" in this course on computer programming. The lower relative performance may be indicative of weaker performance of EE students in computer programming relative to Computer Science majors (it should be noted that the average grade for EECS 280 is consistent with 200-level EECS courses including EECS 215 and EECS 216).

Correlations between choice of subdiscipline in EE (defined by chosen senior capstone course) on performance in early required courses were also studied. The relative performance in the required courses (course grade relative to graduating GPA, on a 4-point scale) were examined for groups of students in different subdisciplines as identified by choice of senior capstone design according to

$$\Delta_{\mathrm{GPA}} = \mathrm{GPA}_{\mathrm{class}} - \mathrm{GPA}_{\mathrm{graduation}} \tag{1}$$

where Δ_{GPA} is the relative performance metric of a particular subdiscipline, $\mathrm{GPA}_{\mathrm{class}}$ is the grade associated with that class for that subdiscipline, and $\mathrm{GPA}_{\mathrm{graduation}}$ is the graduating GPA. The Δ_{GPA} provides a way of comparing class performance across subdisciplines to a score that is normalized to graduating GPA. The statistical significance of relative performance in required courses was compared for varying groups using ANOVA analysis, as shown in Table III. These groups included the subdisciplines defined above. No statistically significant differences between groups for the required math and physics courses were observed. However, all of the required EECS courses demonstrated a statistically significant difference between groups, indicated with p-values < 0.05. The low probability for association of relative performance in math and physics courses with subdiscipline suggests that these courses

TABLE IV
SCHEFFE POST-HOC ANALYSIS TO COMPARE RELATIVE PERFORMANCE IN REQUIRED EECS COURSES FOR STUDENTS IN ONE GROUP TO STUDENTS IN OTHER GROUPS

Other Design

EECS 215	Δ_{GPA}	***p*-value**
Circuits/Solid-State	-0.253	**.004**
Electromagnetics/Optics	-0.160	.271
Signals/Systems	-0.232	**.012**
Computers	-0.244	**.027**
EECS 230		
Circuits/Solid-State	-0.234	**.009**
Electromagnetics/Optics	-0.319	**<.001**
Signals/Systems	-0.198	**.044**
Computers	-0.244	**.019**

Computers

EECS 280	Δ_{GPA}	***p*-value**
Circuits/Solid-State	0.233	**.009**
Electromagnetics/Optics	0.291	**<.002**
Signals/Systems	0.183	.056
Other Design	0.252	.143

Circuits/Solid State

EECS 320	Δ_{GPA}	***p*-value**
Electromagnetics/Optics	0.150	**.012**
Signals/Systems	0.128	**.004**
Computers	0.164	**.009**
Other Design	0.188	**.049**

Signals/Systems

EECS 216	Δ_{GPA}	***p*-value**
Circuits/Solid-State	0.067	.840
Electromagnetics/Optics	0.250	**.007**
Computers	0.080	.910
Other Design	0.274	.213
EECS 401		
Circuits/Solid-State	0.133	.191
Electromagnetics/Optics	0.086	.759
Computers	-0.007	1.000
Other Design	0.203	.383

do not have a clear impact on later curricular choices. However, all of the required EECS courses demonstrate a statistically significant association of relative course performance with subdiscipline, highlighting the potential impact of these courses on later curricular choices.

Multiple comparisons were examined using Scheffe post-hoc analysis for all required courses that demonstrated statistically significant differences $p < 0.05$) between groups (all required EECS courses), as shown in Table IV. The analysis compares student performance in courses between groups defined according to choice of senior capstone design (subdiscipline). The analysis highlights cases where significance is probable, warranting further attention and discussion of behavior or per-

TABLE V
CHI-SQUARE ANALYSIS TO TEST ASSOCIATION OF GENDER OR SUBDISCIPLINE LISTED DEPENDENT VARIABLES

Participatory activity for dependency test	**Gender *p*-value**	**Subdiscipline *p*-value**
Student organization	.693	.690
Student project team	.693	.557
Research project	**.069**	.491
Internship/co-op	.405	**.003**

formance for particular subdisciplines in EE. These cases are described in the following sections.

Senior Capstone Design Outside of EE: Students may choose a senior capstone design course outside of EECS, which may be a multidisciplinary design project or senior capstone design from another department. These students exhibit relative performance that is statistically lower than other students in EECS 215 and EECS 230; these students perform approximately 0.25 grade points below other groups in these two classes. The trend in student performance when choosing a capstone design outside of EE may suggest students decide to pursue other directions because of lower performance compared to their peers.

Students in Computers, Circuits/Solid State: Students choosing a capstone design course in computers demonstrate higher relative performance in the EECS 280 programming course, while students choosing a capstone design course in circuits/solid state demonstrate higher relative performance in the EECS 320 semiconductor device course, relative to other students in EE. These indicate that success and relative performance in EECS 280 and EECS 320 may be strong predictors for choice of subdiscipline in EE.

Signals and Systems: The EECS 216 signals and systems course and EECS 401 course on probabilistic methods represent the required courses in the signals and systems area. While increased relative performance was observed in these courses for students choosing a capstone design course in signals and systems, the ANOVA analysis did not suggest statistical significance. One possible explanation is that the signals and systems capstone design course is considered the most general or least specialized of the EECS senior design courses to choose from, and may be disconnected from interest or performance in a given subdiscipline.

Comparisons of the subdisciplines show strong correlations for select subdiscipline and course combinations such as circuits/solid state and EECS 320. For these combinations, course performance may be highly influential in student motivation for choosing an EE subdiscipline or choosing a discipline outside of EE, which is consistent with expectancy-value theory. These data suggest that students may pursue specific subdisciplines based on their success in the early classes. This yields another element to student motivation to choose a subdicipline that augments the social interactions that students reported in focus groups.

Academic success, beyond GPA, may also be gauged based on participation in professional activities. Potential relationships between student achievement (GPA) and participation in

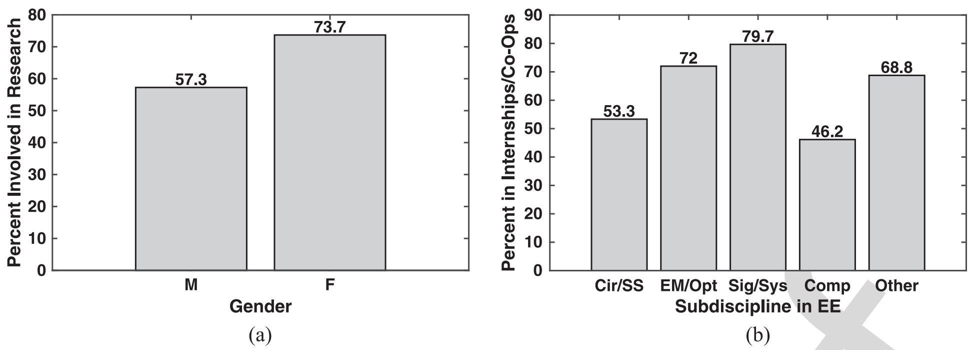

Fig. 3. Survey results for cases where association is suggested between participation in student activities and (a) gender and (b) the subdisciplines—circuits/solid state (Cir/SS), electromagnetics/optics (EM/Opt), signals and systems (Sig/Sys), and computers (Comp).

activities outside of the classroom did not suggest a clear association (Table II). However, an understanding of the behavior of students across different groups may show differences related to motivations and preferences to guide academic curricula and initiatives. Comparisons between these groups based on a chi-square test for independence are summarized in Table V. Overall, the analysis does not suggest significant association between participation in student activities and gender or subdiscipline. However, there is a possible association between gender and participation in research, as well as a strong possible association between student participation in student internships subdiscipline within EE. The numerical results for these two possible associations are shown in Fig. 3. The fraction of female student participation in research is higher than for male students, a statistic that is encouraging for EE where female students are still vastly underrepresented. The fraction of students in each subdiscipline also shows significant variability, with particularly low participation for students in circuits/solid state and computers, and particularly high participation for students in the signals/systems. Further analysis is needed to determine if/how this participation relates to motivations and values for students in the various subdisciplines, and possible connection to market forces in these subdisciplines.

IV. Conclusion

One of the primary research objectives of this study was to examine reasons that students cite for choosing EE as a major. Based on the study, students' motivations for choosing an EE major are largely influenced by inherent interest in the subject matter and future professional opportunities. The findings for student motivation are consistent with the expectancy-value theory [8]–[11], with greatest weight on anticipated value of the professional opportunities provided by the EE degree. Environmental factors, including family, friends, and faculty, also play a role in student motivations, consistent with the influence of socializers on an individual's expectancies and values [9]. Motivation impacts student choices, including choice of major, elective courses, and student activities, highlighting the importance of examining motivations for students to choose EE and the education experience together.

The second related research objective of this study was to examine how student performance in EE relates to demographics and curricular choices. The data analyzed in this study indicate that student performance and participation in student activities do not appear to be associated with gender or parental educational background for students in the EE program. Performance in early required courses in math and physics serve as strong predictors for future academic success, but not necessarily choice of subdiscipline in EE. In contrast, relative performance in select required courses in the EE program serves as a predictor for choice of subdiscipline, which provides further insight into student motivation. Participation in student activities generally does not show statistically significant association with gender or subdiscipline, with the exceptions of participation of research projects with respect to gender and participation in internships/co-ops with respect to subdiscipline. The varying correlations, or lack of correlations, between subdisciplines suggest that factors beyond grade performance play a role in student behavior. In particular, social factors may play a role in explaining these variations (consistent with the influence of socializers on expectancy-value [9]), and may strongly influence student decisions with possible differences between the EE subdisciplines.

The studies indicate that primary motivating factors in determining choice of EE major and subdiscipline are a strong perceived value of professional opportunities afforded by the technical area, and social influences, including specific faculty instructors. Early interactions with students before they declare EE or subdiscipline in EE can strongly motivate curricular and co-curricular choices and professional activities. These factors are likely to apply broadly to student populations beyond the University of Michigan. The findings suggest that it is imperative to connect with students early in their academic pursuits to positively influence student choices, as this may improve student recruiting and retention. Specifically at the University of Michigan, emphasis will be given to assigning the most outstanding instructors to early required courses, as active learning has been shown to increase student performance [14],[15], with anticipated increase in student motivation according to expectancy-value theory. Further recommended efforts are to expand exposure of EE-related concepts in first-year engineering courses and to hold targeted informational events to showcase professional opportunities for EE majors and associated subdisciplines. Given that motivations can be largely shaped by early curricular experience, revising the curriculum to offer a more blended or integrated teaching of EE technical areas in early courses may provide a more optimal means of connecting with students than conventional modes of teaching topical areas in separate courses in a sequential manner. Such curricular reform may provide a means for students to make connections between technical areas while also providing a more impartial exposure to EE subdisciplines, ultimately equipping students with more accurate perceptions upon which to base future curricular and professional decisions.

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