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Identifying Causal Configurations for Engineering Graduate Student Attrition Outcomes Using Qualitative Comparative Analysis

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ABSTRACT

The statistics surrounding graduate engineering student attrition are staggering and have seen little to no improvement in past years. The Council of Graduate Schools reports a 24 percent attrition rate for men and a 35 percent rate for women (Council of Graduate Schools, 2008). Rates are only higher among students who fall into minority groups (Sowell et al., 2015). While past research had identified prevalent factors that strongly influence doctoral students' decision to remain in or depart from their Ph.D. programs, this study aims to identify how these factors work together to form common pathways to student attrition outcomes including questioning, departure, and persistence. Interviews were conducted with engineering graduate students (N=41) from the top 50 engineering Ph.D. granting universities who had previously or were currently considering leaving their program along with students who had already departed. Participant were asked to share their personal experience in graduate school including their path into graduate school, relationships with advisors and peers, experiences with research, perceived costs, and how their experiences contributed to their thoughts about leaving. Student narratives were used to craft quantitative input data to be analyzed using Qualitative Comparative Analysis (QCA) in order to identify combinations of factors which frequently lead to the same student attrition outcomes. QCA has long been used in social sciences but this is the first study to apply the method to engineering education. Findings indicate that while engineering graduate student experiences are varied, common pathways to questioning, departing, and persisting exist and are made up of multiple attrition factors acting simultaneously. In addition, results indicate that the combinations that most heavily influence men and women differ. The findings of this study contribute to the growing body of graduate engineering education literature and provide a deeper

understanding of how graduate engineering students, graduate advisors, and university engineering departments can develop better practices to ameliorate graduate engineering attrition and to ensure that graduate engineering students are receiving the necessary support and tools to achieve success.

TABLE OF CONTENTS

LIST OF TABLES iv

ACKNOWLEDGEMENTS v

Chapter 1 Literature Review 1

Chapter 2 Methods 8

- Recruitment, Selection, and Interview Conduction 8
- Qualitative Interview Analysis 10
- Qualitative Comparative Analysis 11
- Fuzzy Set Membership Definitions in Evaluating Graduate Attrition 13
- Crisp Set Membership 15
- Secondary Analysis for Positive Membership Evaluation: Reframing Analysis to Consider Positive Factors Experienced By Persisters 16
- Case Groupings 16
- Limitations 17

Chapter 3 QCA Results 19

- Membership Results 19
- Subset/Superset Analysis 25
- Pathways to Questioning 26
- Pathways to Persistence 29
- Pathways to Departure 30

Chapter 4 Supporting Qualitative Evidence for Causal Configurations 32

- Academic Environment and Cost for Questioners 33
- Differences in Men and Women Questioners 35
- Lack of Support in Persisters 38
- Lack of Clear Goal in Persisters 41
- Research for Departers 43

Chapter 5 Discussion and Conclusions 46

- Implications for Stakeholders 48
- Conclusions 51
- Future Work 52

BIBLIOGRAPHY 54

LIST OF TABLES

Table 1. Participant Demographics..... 9

Table 2. Membership Guide for Advisor Relationship Condition 15

Table 3. Fuzzy set membership 20

Table 4. Crisp set membership 21

Table 5. Fuzzy set membership for positive conditions 22

Table 6. Crisp set membership for positive conditions 23

Table 7. Crisp set causal configurations for questioners 27

Table 8. Fuzzy set causal configurations for questioners 27

Table 9. Differing causal configurations for men and women questioners 28

Table 10. Fuzzy set causal configurations for persisters 29

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Chapter 1

Literature Review

Retention for engineering degree programs across the US is incredibly low. In fact, retention rates have consistently been in the range of 50% for the last 70 years (Geisinger & Raman, 2013), indicating that nearly half of all students who enter an engineering program, at any degree level, in the US do not graduate from that program. At the graduate level, 24-35% of students do not complete their course of study (Council of Graduate Schools, 2008), with even higher rates of attrition for students—over 50%—from minoritized groups (Sowell et al., 2015).

The high attrition rates in engineering education are problematic for multiple reasons. The need for increased numbers of engineers in the workforce to maintain and advance the highly technological societies in which we live has been acknowledged (Golde & Dore, 2001).With such high percentages of students not completing the engineering studies which they enter into, the ability to produce new trained professionals coming out of universities to fill this need is impeded. Additionally, engineers are tasked with helping to solve global problems, an undertaking that requires a great deal of collaboration from diverse thinkers. “Diversity” here includes the full participation in engineering from underrepresented racial and ethnic groups and genders as well as diversity by the lived experiences of a single individual (Wulf, 2002). The lack of diversity among engineering graduates has long been noted and has, in part, been attributed to the inability to retain students in the earlier stages of their engineering studies, a phenomenon known as the “leaky pipeline” theory for underrepresentation (Shuman et al.,

1999). As such, engineering graduates being sent out into the workforce are tackling big problems with a primarily uniform perspective and way of thinking.

Another ramification of the leaky pipeline at the graduate level is that a lack of diversity in graduate populations, and the inability to retain a diverse population of graduate students, yields underrepresentation in future generations of administrators, researchers, and educators in higher education. With environments that do not support and encourage students in their studies, there is potential that we are missing out on students who could be brilliant educators (Golde & Dore, 2001). Attrition rates for underrepresented groups in engineering graduate programs have reached percentages as high as 57% (Sowell et al., 2015), meaning that there is also a blatant lack of diversity among future educators. Lack of faculty diversity is a problem which continues to propagate additional problems in the education system. One such example is the lack of role models in academia for young students from underrepresented groups (Golde & Dore, 2001), further perpetuating lack of support for traditionally underserved students in engineering.

Additionally, high rates of attrition prove to be costly for universities both in terms of human resources and other departmental resources especially in graduate programs. Funding and individual faculty time put toward advancing a student toward a degree, which they ultimately do not complete, may have been better allocated elsewhere (Golde, 1994). For universities and departments, losing graduate students also means potentially losing years of experience and knowledge that are valuable because graduate students often teach lower level courses and are integral parts of advancing research projects (Ampaw & Jaeger, 2012).

Graduate studies in particular have been identified to be especially adverse environments that push high numbers of students toward the decision to drop out. In a report published by Golde and Dore (2001), it was reported that many graduate students feel both unprepared when

entering into graduate studies and that their graduate studies are not adequately preparing them to succeed in their intended future career. Students who ultimately depart from their graduate studies are faced with a loss of time and money and often face a great deal of emotional guilt and shame (Berdanier et al., 2020; Devine & Hunter, 2016). Such sentiments indicate a failure on both the part of undergraduate programs as well as the graduate programs themselves. Yet, despite broad acknowledgement of the problems surrounding the inability to retain students in their engineering degree programs, there exists little research exploring why attrition rates are so high, the factors that contribute to students leaving or remaining in their programs, and the ways in which higher education can be improved to yield more graduates in engineering programs. Sustained high attrition rates are indicative of a lack of understanding of the contributors to program departure and a lack of proposed recommendations that are effective at addressing and mitigating any identified contributing factors. This is especially true in the sphere of engineering graduate programs.

In the last two decades, researchers in the field of graduate-level education have begun to turn some focus onto the topic of graduate student attrition, realizing the many faults and flaws in current graduate school programs relevant to all disciplines. In a report released by Golde and Dore (2001) a summary of the ways in which graduate school education is working and the ways in which it is not is presented and they put forth recommendations for improvement.

Most research has centered around determining variables that impact attrition that are controllable by universities or the specific program departments. Institutional variables center largely around the cultivated environment of specific graduate programs. Research has indicated that socialization processes, program culture and quality, and student support services all play a role in retaining graduate students (Gardner, 2008; Lovitts, 1996). In the past, universities have

attempted to place a larger emphasis on admissions decisions, thinking that selecting more qualified students would lead to lower attrition rates. Yet, the problem persists, indicating that attrition is largely tied to a student's experiences within their graduate program, rather than their developed qualifications or experiences prior to entering graduate school (Lovitts, 1996).

In another sphere of research, emphasis has been placed on personal and psychological factors that are likely to predict program departure. Some of these include a low need for achievement defined by a lack of goal setting and apathy toward accomplishments, an initial intention to quit, high levels of stress, low levels of social support, and experiences of alienation (Cooke et al., 1995). Spaulding and Rockinson-Szapkiw (2012) emphasize personal factors such as motivations for degree pursuit, reasons for persisting, strategies for dissertation completion, and experiential factors such as challenges faced in the dissertation process, personal sacrifice made, and expectations for degree completion delay as integral impactors on the course of a student's years in graduate school. Much of a graduate student's life revolves around their dissertation so it is no surprise that the dissertation process is a large focus of attrition studies. When separating degree completers from non-completers, a primary differentiator among these two groups is feelings of progress and success on an understandable research project without experiencing a great deal of stress (Devos et al., 2017).

Studies on students in doctoral programs have pointed to the importance of socialization and its impact on success and attrition. All too often socialization processes in academic departments are not inclusive to students who fall outside of the stereotypical graduate student profile of a young, white, male, contributing to an overall feeling of not fitting in and therefore a desire to want to depart from a graduate program (Gardner, 2008). Without strong support systems found in an academic environment, students become emotionally exhausted and are

largely discouraged to persist, although the impacts vary in severity across differing academic disciplines (Devine & Hunter, 2016). A great deal of attention has been paid to the influence of the support system found in the student-advisor relationship with at least 15% of current graduate student focused studies exploring the topic (Jones, 2013). The singular relationship between a doctoral student and his or her advisor is identified to be an incredibly complex but telling relationship when it comes to program completion outcomes among doctoral students (Devos et al., 2017).

It is important to note, however, that trends in attrition are not completely transferable across differing degree programs and disciplines. Program structure and expectations can vary across different disciplines, even when looking across science, technology, engineering, and mathematics, a group of disciplines that are typically combined into the overarching "STEM" label (Crede & Borrego, 2013). Graduate students interact with a plethora of embedded communities including communities defined by institution, department, lab, and student-advisor relationship, all which can vary greatly by discipline (White & Nonnamaker, 2011). Integration into these many communities often requires conforming to the norms, values, and attitudes of the group and gaining the necessary knowledge to stay on par with the other members of the community (Weidman & Stein, 2003). Again, such norms, values, attitudes, and necessary knowledge change when observing a multitude of disciplines. Therefore, fully understanding and addressing attrition in graduate engineering programs requires exploration taking into account disciplinary features.

With direction from the National Academies (National Academies, 2018), researchers have been paying more attention to the understudied field of graduate science, technology, engineering and mathematics education. Initial research has focused primarily on identifying

factors that play major roles in pushing graduate students to remain in or leave their course of study. Researchers point toward student-advisor relationship, financial and nonfinancial costs, levels of support, lab integration, and socialization experiences as common factors that highly influence attrition (Ampaw & Jaeger, 2012; Berdanier et al., 2020; Lovitts, 1996). Berdanier et al. (2020) cite two additional contributing factors – perception of others and goals – and further explore the complex relationships between factors influencing attrition noting that the many factors interact over long periods of time leading to the ultimate decision to persist or depart – a sentiment that other studies fail to acknowledge.

While a primary focus of engineering graduate education research has been the identification of factors which lead to a student's decision to depart, there has been little exploration in building pathways to or predictive models of student departure that focuses on relationships between attrition factors rather than viewing them as acting singularly. In part, this lack of research focus can be attributed to the complex decision-making process which engineering graduate students navigate during which they balance consideration of both the past and future, making any sort of predictive model incredibly complex (Cass et al., 2018). Additionally, as Ampaw and Jaeger (2012) point out, doctoral programs can be categorized into three stages – transition, development, and research – all of which contain their own factors which influence students' desires to persist in or depart from their programs at differing levels of severity. Tinto's persistence model, one of the only attempts at constructing a predictive model of attrition, points out time-invariant predictors as well as time-varying predictors to indicate factors that may point to a student's likelihood of departing from their program across time (Tinto, 1993). Yet, what Tinto's model lacks is any sort of indication of how the many factors are connected or interact with each other to lead to the ultimate decision of a student to depart

from their program. In fact, the GRaD model is the only current model which indicates that there is any sort of connection between the factors that have been identified to impact engineering graduate student attrition (Berdanier et al., 2020)

This work aims to build on the existing research in engineering graduate education research that focuses on identifying factors that contribute to a student's decision to depart from their PhD program, particularly on Berdanier's acknowledgement of the interconnectedness of attrition factors. In this investigation, we aim to explore the existence of pathways to student attrition outcomes as influenced by a conglomerate of factors acting together rather than alone. Through analysis of interviews conducted with engineering doctoral students, we posit that pathways crafted by combinations of attrition factors which are sufficient to produce outcomes of questioning or departure can be identified. This work was guided by the following research questions:

1.) What combinations of attrition factors are experienced across students' time spent in engineering PhD programs?
2.) Do particular combinations of attrition factors frequently lead to outcomes of questioning or departure?
3.) Are there factors or combinations of factors that aid in encouraging persistence among engineering graduate students?

Chapter 2

Methods

This study used methods of Qualitative Comparative Analysis to analyze interview data from current and former graduate students across the United States at Research Intensive universities. To define terminology, this work employs verbiage to describe participants' trajectories. Participants are characterized into "persisters"—those who will likely complete their degrees; "questioners"—those who are actively deciding whether to depart from their engineering PhD program with a Master's degree; and "departers," those who have left (or have filed the paperwork to leave) their programs.

Recruitment, Selection, and Interview Conduction

ASEE's list of top engineering PhD granting institutions (Roy, 2019) was used to identify 50 universities from which participants would be recruited. A recruitment survey was sent to department heads and program coordinators at each of the 50 universities requesting that the survey be disseminated to their respective student body. The survey asked students to identify the extent to which they had considered departing from their PhD program. The survey also asked students to identify conditions that influence success in graduate school and conditions that had significantly impacted their graduate experience on a personal level. Additionally, demographic information was collected through the survey. A total N=636 students completed the survey over the course of multiple semesters. At the end of the survey, participants could indicate interest in participating in an interview if selected.

Maximum variation sampling was used to select participants to interview, based on gender, ethnicity, considerations of departure, and years in graduate school. A total of N=41 participants were interviewed and the demographics of the interview participants are presented in Table 1. All participants selected for interviewing were permanent residents or citizens of the United States. The decision to select only permanent residents or citizens of the United States was made because it is well understood that the experiences of international students in US graduate programs differs significantly from that of US natives. For this study, we focused only on the experiences of US native students. Interviews lasting one to two hours in length were conducted using Zoom videoconferencing platform and were audio recorded to be transcribed by a professional service.

Table 1. Participant Demographics

Gender	
Men	16
Women	23
Non-Binary	1
Another Gender	1
Ethnicity	
Latinx	2
Black or African-American	1
Asian	2
White/Caucasian	30
Bi-Racial	6
Years in Graduate School	
1-2	14
3-4	18
5+	9

The semi-structured interview protocol asked participants to share how they selected their graduate school, program, and advisors as well as what their goals were heading into graduate school. Seeking to get a picture of each participant's experience while in graduate school,

participants were also asked to describe their advisor relationship, experiences with research, support systems, working environment, quality of life, and perceived costs of graduate school. Participants were additionally asked to identify their feelings toward departing from their program with or without a Master's degree. The interviews were semi-structured, allowing the participants to best share their unique story to and through graduate school beyond topics that were outlined in the interview protocol. Most participants readily shared their experiences and reasons for considering leaving or persisting in their graduate studies. The semi-structured nature of the interview protocol allowed interviewers to ask follow up questions and probe more deeply into interpretations of situations.

It is difficult to recruit people who have left their PhD programs. Departers are essentially an invisible population of students and are a difficult group to identify and recruit. Therefore, at the end of each interview, the researchers used snowball sampling methods to ask participants to forward our recruitment requests to other questioners and departers in the participants' personal and professional networks.

Qualitative Interview Analysis

The interview transcripts of each of the 41 participants were used to identify conditions that were mentioned in congruence with a student's decision to question, persist, or depart from their program. The first round of quantitative interview analysis focused on noting variables that were common across all participants. Eight conditions that frequently influenced participant's feelings toward departing were identified – advisor relationship, quality of life, clarity of goal, satisfaction in research, academic environment, academic support, social support, and costs.

Many of the identified conditions were topics that were explicitly included in the interview protocol.

Each interview was then coded to identify the presence of each of the eight conditions, paying attention to note whether a student indicated a positive or negative valence when discussing each condition. Additionally, any unique aspects of a student's story that may have contributed to their path to, in, and through graduate school were noted. For example, some participants cited the influence of their involvement in mentorship programs for younger students on their motivation to persist despite hardships.

Qualitative Comparative Analysis

Qualitative Comparative Analysis is a method that utilizes both qualitative and quantitative techniques to analyze outcomes. Originally created for use in political science and historical sociology research, prior work from our group has proven the usability of QCA for research in the field of engineering education (Hocker, 2020). Utilizing QCA relies on a deep understanding of the cases being analyzed in order to represent each case as causal and outcome conditions. In the case of this study, deep understanding was achieved through the conduction and condition analysis of attrition factors within participant interviews. Using software designed for QCA, causal configurations, or combinations of conditions that lead to the same outcomes, can be generated. Each causal configuration is assessed on the basis of *necessity* and *sufficiency*. Necessity indicates whether a causal configuration must be present in order to produce an outcome whereas sufficiency indicates whether or not a casual configuration is sufficient to produce an outcome. The purpose of QCA is to understand how conditions interact to produce

certain outcomes rather than emphasizing any one condition as having incremental impact on the production of outcomes.

QCA functions on assigned membership scores for conditions and outcomes. Multiple methods of membership evaluation can be facilitated through QCA. For this study, both crisp set and fuzzy set membership evaluation was used. Crisp set QCA (csQCA) utilizes a binary system for assigning cases to membership of identified conditions. Assigning a case full membership (1) indicates that a particular condition was found to be present for the case. In contrast, assigning a case non-membership (0) indicates that the condition of interest was absent for the particular case. In the case of participants who note a negative relationship with their research advisor in their decision to consider departure from their PhD, in csQCA, they would be an assigned a 1, indicating that the "poor advisor relationship" was present. If, conversely, a participant noted a strong and healthy advisor relationship, the factor would be assigned a membership value of zero, indicating that it did not meet full membership. The binary logic of csQCA can be helpful in determining some trends, but is inherently limited in assessing belonging for complex cases.

To overcome these limitations, fuzzy set QCA (fsQCA) was developed to facilitate multiple degrees of membership. As in csQCA, a membership value of 1 indicates full membership and a membership value of zero indicates non-membership. However, in fsQCA, the researcher may decide to use any number of levels to evaluate degrees of membership evaluation. For this study, fuzzy set membership evaluation was performed using five values. The five-value scheme assigns cases 0.25 an 0.75 to indicate membership that is "more out than in" and inversely "more in than out." A membership score of 0.5 is assigned to cases for there is maximum ambiguity. In the case of fuzzy-set, it is important to note that membership scores are not used to rank cases against each other, but rather identify distinct qualitative states of

membership. Again, calling on the advisor relationship example, researchers can assess the valence of the relationship overall—not trying to decide if it is wholly positive or negative—and instead assign a value of 0.75 (the relationship, based on the participant's perspective is more negative than positive) or 0.5 (equally negative and positive), or 0.25 (more positive than negative) as well as full or null membership. It is clear how fsQCA is more useful in determining causal configurations for studies of human experiences.

Fuzzy Set Membership Definitions in Evaluating Graduate Attrition

In this study, fuzzy set membership scores were assigned first. For each of the conditions, specific attributes for each condition were identified which would aid in defining membership for each case. For example, the attributes for advisor relationship included availability, personality, mentorship, and advising style. The interview coding was used to assign a positive or negative valence to each attribute. A membership guide was created for fuzzy-set membership evaluation to outline what defined full membership, non-membership, mostly-full membership, mostly non-membership, and inconclusive/neutral membership based on the valence of each attribute for each condition. Membership could then be assigned to each case for each condition as outlined by the membership guide to represent each case as a series of causal and outcomes conditions. Outcomes were assigned only binary membership determined by participants' identification as a questioner, persister, or departer from their PhD program.

Some attributes were difficult to assign membership, because of individual preferences and which features participants discussed (a function of the semi-structured nature of the interview). For example, when students discussed their relationship with their advisor, some

students mentioned attributes of personality, availability, and mentorship. However, not all students mentioned all of these attributes when discussing their advisor relationship, and valence was difficult to assign. For conditions in which this was the case, an alternative method to assigning membership was developed. As before, a positive or negative valence was assigned to each criteria attribute which were discussed in the participant interview. Attributes which were not discussed during the interview were not assigned a valence. For example, if a participant did not discuss their advisor as a mentor, a zero was assigned to the mentorship attribute. In other cases, no valence could be assigned even if the attribute was discussed because the participant did not explicitly indicate their favorable preference. For example, when assessing a student's opinion of their advisor's overall advising style, participants mentioned that their advisor's style was hands-off. For some students, a hands-off advising style may have been preferable, while for others it may have been not preferred. Unless a student explicitly indicated their preference and a misalignment or that they either enjoyed or disliked said characteristic, the characteristic was not assigned a valence, but rather given a score of zero.

Fuzzy set membership could then be assigned by weighing the positive and negative valences against each other. For a participant that mentioned only attributes with negative valences, full membership was assigned and inversely those that mentioned only positive attributes were assigned non-membership. For students disqualified from non-membership and full-membership, mostly-full membership was assigned to cases where there were more negative than positive attributes discussed and mostly non-membership was assigned to cases were more positive than negative attributes were listed. Inconclusive or neutral membership was assigned to those cases were there were an equal number of positive and negative attributes discussed or there was not enough information provided in the interview to assess the condition. An example

of fuzzy-set membership criteria for the condition of "Negative Advisor Relationship" is shown in Table 2.

Table 2. Membership Guide for Advisor Relationship Condition

Negative Advisor Relationship	
Full Membership (1)	Only negative advising characteristics mentioned or explicit statement of strong dissatisfaction with advisor
Mostly-Full Membership (0.75)	Disqualified for both full membership and full non-membership and mentioned more negative than positive advising characteristics
Inconclusive or Neutral (0.5)	Equal number of negative and positive advising characteristics or inadequate amount of data to determine advisor relationship satisfaction
Mostly Non-Membership (0.25)	Disqualified for both full membership and full non-membership and mentioned more positive than negative advising characteristics
Non-Membership (0)	Only positive advising characteristics mentioned or explicit statement of strong satisfaction with advisor

Crisp Set Membership

Crisp set membership scores were assigned secondarily using the same membership guide while removing the possibility to assign inconclusive or neutral membership. Therefore, a stricter evaluation of membership is performed in which a condition would be assigned non-membership even if it met most criteria for full membership. In order to qualify for full membership, all criteria must be met. Similarly, for conditions which were previously assigned inconclusive membership, non-membership is now assigned to that condition.

Secondary Analysis for Positive Membership Evaluation: Reframing Analysis to Consider Positive Factors Experienced By Persisters

In order to identify the conditions that persisters experienced which positively contributed to their overall experience in graduate school and kept them forging forward to finish their degree, membership evaluation was additionally performed for positive conditions. Whereas previously, membership was evaluated for conditions such as *poor* advisor relationship, *strong* advisor relationship was now evaluated to determine membership values. This form of positive condition membership evaluation was performed for all persisters using both fuzzy set and crisp set. The method of membership evaluation was performed specifically for persisters as this group of students was identified as the group that we can learn the most from in terms of what is working well in the graduate student experience to keep students in their programs. However, in order to facilitate the proper analysis within the QCA software, all cases had to be evaluated for positive experiences.

Case Groupings

It was of interest to this study to understand how graduate school experiences might differ between students from different demographics including gender and ethnicity as well as students who came from non-engineering undergraduate programs or students who returned to graduate school after spending time in industry or elsewhere. For this reason, along with evaluating the membership data for all cases, cases were grouped by various demographics including gender, minority ethnicities, disciplinary outsiders, and academic returners. Each set of data was evaluated using fsQCA software to generate causal configurations which resulted in each of the three outcomes – questioning, departure, and persistence.

Limitations

As with all research, there are limitations related to recruitment, selection, and methods choices. Interviews were conducted in a semi-structured interview format and therefore not every participant touched on or delved deeply into the same topics. While a participant may have had prominent experiences, for example, in struggling with their research, they may not have discussed these experiences due to the structure of the interview. Later in the study, it would then be assumed that because a participant did not discuss their research, that they did not perceive any issues in that particular area to be salient to their decisions and experiences. Similarly, the interviews cannot capture all a participant's experiences, such that the narratives and experiences recounted are assumed to be those that were most formative in a student's decision.

Additionally, the recruitment process likely contains an element of self-selection bias. Participant interviews were conducted on those survey participants who indicated that they would be open to discussing their experience in graduate school in an interview. Therefore, it is likely that only students who wished to share their experiences expressed interest in being interviewed. While multiple variation sampling allowed for the selection of as wide an array of experiences as possible, there may still be experiences that are common that were not present in our data set. Although a participant size of N=41 is quite large for in-depth qualitative interview methods, it is still not large enough to be predictive or generalizable for all engineering graduate students. Themes, though, viewed through theory and leveraged with additional literature, do allow researchers to show how findings can enhance engineering education research and practice.

Using QCA to analyze data presents its own limitations. The process of determining membership is largely subjective to the researcher to determine what qualifies as full, partial, or

non-membership. The same set of data, given to another researcher, could result in a different determination of membership. A clear membership evaluation guide was established by the researcher for the data used in this study as a method of overcoming the challenge of subjectivity.

Further, simply determining membership provided its own challenges as a result of the interview process. It was mentioned previously that not every participant touched on all of the conditions that were evaluated in this study. Additionally, when discussing a condition, not every student mentioned the same attributes. This necessitated a method of weighing positives and negatives, a method developed by Hocker (2020), to determine membership for some of the conditions such as advisor relationship. While this is not a common practice for the use of QCA, for the given data it was an appropriate method of determining the degree to which a student faced challenges in a particular area of their graduate experience.

Chapter 3

QCA Results

Membership Results

Membership evaluation produced quantitative data for each participant case. The data presents each participant's experience as a series of numerical values which summarizes whether or not a student experienced each of the eight conditions, and to what degree they experienced each condition for the fuzzy set data. The quantitative data additionally indicates which outcome each student was categorized into. Each participant case configuration for both fuzzy set and crisp set are presented below in Tables 3 and 4. Additionally, Tables 5 and 6 present the fuzzy and crisp set positive condition membership evaluation for all participants.

Table 3. Fuzzy set membership

	Persister	Questioner	Departer	PoorAdvisorRelation	PoorQualofLife	LackofClearGoal	DislikeofResearch	NegAcaEnvironment	LackofAcaSupport	LackofSocialSupport	Costs
Case 1	0	1	0	0.25	0.25	0	0.75	0	0.5	0.25	1
Case 2	0	1	0	0	0.75	1	0	1	0.25	0.25	1
Case 3	0	1	0	0	0.75	0.25	0.75	1	0.25	0.5	0
Case 4	0	1	0	0	0.75	0	0	0.75	0.25	0.5	0
Case 5	0	1	0	0	0.75	0	0.25	1	0	0.25	1
Case 6	0	1	0	0.75	1	0	0.5	1	0.75	0.25	1
Case 7	0	1	0	0	0.5	0.75	1	0	0.5	0.25	1
Case 8	0	1	0	0.5	0.25	0.25	0	0	0.25	0	1
Case 9	0	1	0	0.75	0.75	0.25	0.75	1	1	0	0
Case 10	0	1	0	0.5	0.25	1	0.75	1	0.75	0.25	1
Case 11	0	1	0	0.75	0	0.25	0.75	1	0.5	0.25	1
Case 12	0	1	0	0.25	1	1	0.75	0.75	0.25	0.5	1
Case 13	0	1	0	0.5	1	1	0.75	0.75	0.5	0.5	1
Case 14	0	1	0	0	0	0.75	1	1	0	0.5	1
Case 15	0	1	0	0	0.75	1	0.75	0.5	0.5	0.5	0
Case 16	0	1	0	0	0	0.25	0.5	1	0	0.5	0
Case 17	0	1	0	1	1	0	0	1	0.5	0.5	0
Case 18	0	1	0	0	0.25	0.75	0.5	0	0.5	0.5	1
Case 19	0	1	0	1	0	0.75	0.25	0.5	0.5	0	0
Case 20	0	1	0	0.25	0.25	0.25	0.75	0.5	0.25	0.25	1
Case 21	0	1	0	0.5	0.25	0	0.5	0	0.5	0.5	0.25
Case 22	0	1	0	1	0.75	1	0.25	0	0.5	0.5	1
Case 23	0	1	0	1	1	0.25	0	1	0.5	0.5	1
Case 24	0	0	1	1	0	1	0	0	0.75	0	1
Case 25	0	0	1	0.5	0.75	0	1	1	0.75	0.25	0
Case 26	0	0	1	1	0.75	0.75	0	1	0.25	0.25	1
Case 27	0	0	1	0.5	0.75	1	1	0	1	0	1
Case 28	0	0	1	0.75	0.75	0	1	0	0.5	0.25	1
Case 29	0	0	1	0.75	1	0.75	1	1	0.75	0	1
Case 30	0	0	1	0.75	0.75	0.5	1	0.5	0	0.25	0
Case 31	1	0	0	0.75	0.75	0.25	1	1	1	0.5	0
Case 32	1	0	0	0.25	0.75	0.5	0.5	1	0.25	0.25	0
Case 33	1	0	0	1	0.75	0.25	0.75	1	0.5	0.5	0
Case 34	1	0	0	0	0.75	0.25	0	0.5	0.5	0.25	1
Case 35	1	0	0	0.5	0.75	1	0	0.25	0	0.25	1
Case 36	1	0	0	0.75	0.75	0.75	1	1	0.75	0.25	1
Case 37	1	0	0	0.25	0.75	0.75	0	0.5	0.75	0.25	0
Case 38	1	0	0	0.25	0	1	0	0.5	0	0.25	1
Case 39	1	0	0	0	0	1	0	1	0.25	0.25	1
Case 40	1	0	0	0.5	0.5	1	0.75	1	0.5	0	1
Case 41	1	0	0	0.25	0.75	0.75	0.25	1	0.25	0.5	0

Table 4. Crisp set membership

	Persister	Questioner	Departer	NegativeAdvisorRelation	PoorQualityofLife	LackofClearGoal	DislikeofResearch	NegativeAcaEnvironment	LackofAcaSupport	LackofSocialSupport	Cost
Case 1	0	1	0	0	0	0	0	0	0	0	1
Case 2	0	1	0	0	0	1	0	1	0	0	1
Case 3	0	1	0	0	0	0	0	1	0	0	0
Case 4	0	1	0	0	0	0	0	0	0	0	0
Case 5	0	1	0	0	0	0	0	1	0	0	1
Case 6	0	1	0	0	1	0	0	1	0	0	1
Case 7	0	1	0	0	0	0	1	0	0	0	1
Case 8	0	1	0	0	0	0	0	0	0	0	1
Case 9	0	1	0	0	0	0	0	1	1	0	0
Case 10	0	1	0	0	0	1	0	1	0	0	1
Case 11	0	1	0	0	0	0	0	1	0	0	1
Case 12	0	1	0	0	1	1	0	0	0	0	1
Case 13	0	1	0	0	1	1	0	0	0	0	1
Case 14	0	1	0	0	0	0	1	1	0	0	1
Case 15	0	1	0	0	0	1	0	0	0	0	0
Case 16	0	1	0	0	0	0	0	1	0	0	0
Case 17	0	1	0	1	1	0	0	1	0	0	0
Case 18	0	1	0	0	0	0	0	0	0	0	1
Case 19	0	1	0	1	0	0	0	0	0	0	0
Case 20	0	1	0	0	0	0	0	0	0	0	1
Case 21	0	1	0	0	0	0	0	0	0	0	0
Case 22	0	1	0	1	0	1	0	0	0	0	1
Case 23	0	1	0	1	1	0	0	1	0	0	1
Case 24	0	0	1	1	0	1	0	0	0	0	1
Case 25	0	0	1	0	0	0	1	1	0	0	0
Case 26	0	0	1	1	0	0	0	1	0	0	1
Case 27	0	0	1	0	0	1	1	0	1	0	1
Case 28	0	0	1	0	0	0	1	0	0	0	1
Case 29	0	0	1	0	1	0	1	1	0	0	1
Case 30	0	0	1	0	0	0	1	0	0	0	0
Case 31	1	0	0	0	0	0	1	1	1	0	0
Case 32	1	0	0	0	0	0	0	1	0	0	0
Case 33	1	0	0	1	0	0	0	1	0	0	0
Case 34	1	0	0	0	0	0	0	0	0	0	1
Case 35	1	0	0	0	0	1	0	0	0	0	1
Case 36	1	0	0	0	0	0	1	1	0	0	1
Case 37	1	0	0	0	0	0	0	0	0	0	0
Case 38	1	0	0	0	0	1	0	0	0	0	1
Case 39	1	0	0	0	0	1	0	1	0	0	1
Case 40	1	0	0	0	0	1	0	1	0	0	1
Case 41	1	0	0	0	0	0	0	1	0	0	0

Table 5. Fuzzy set membership for positive conditions

	Persistor	Questioner	Departer	StrongAdvisorRelation	GoodQualofLife	ClearGoal	LikesResearch	PosAcaEnvironment	StrongAcaSupport	StrongSocialSupport	NoCosts
Case 1	0	1	0	0.75	0.75	1	0.25	1	0.5	0.75	0
Case 2	0	1	0	1	0.25	0	1	0	0.75	0.75	0
Case 3	0	1	0	1	0.25	0.75	0.25	0	0.75	0.5	1
Case 4	0	1	0	1	0.25	1	1	0.25	0.75	0.5	1
Case 5	0	1	0	1	0.25	1	0.75	0	1	0.75	0
Case 6	0	1	0	0.25	0	1	0.5	0	0.25	0.75	0
Case 7	0	1	0	1	0.5	0.25	0	1	0.5	0.75	0
Case 8	0	1	0	0.5	0.75	0.75	1	1	0.75	1	0
Case 9	0	1	0	0.25	0.25	0.75	0.25	0	0	1	1
Case 10	0	1	0	0.5	0.75	0	0.25	0	0.25	0.75	0
Case 11	0	1	0	0.25	1	0.75	0.25	0	0.5	0.75	0
Case 12	0	1	0	0.75	0	0	0.25	0.25	0.75	0.5	0
Case 13	0	1	0	0.5	0	0	0.25	0.25	0.5	0.5	0
Case 14	0	1	0	1	1	0.25	0	0	1	0.5	0
Case 15	0	1	0	1	0.25	0	0.25	0.5	0.5	0.5	1
Case 16	0	1	0	1	1	0.75	0.5	0	1	0.5	1
Case 17	0	1	0	0	0	1	1	0	0.5	0.5	1
Case 18	0	1	0	1	0.75	0.25	0.5	1	0.5	0.5	0
Case 19	0	1	0	0	1	0.25	0.75	0.5	0.5	1	1
Case 20	0	1	0	0.75	0.75	0.75	0.25	0.5	0.75	0.75	0
Case 21	0	1	0	0.5	0.75	1	0.5	1	0.5	0.5	0.75
Case 22	0	1	0	0	0.25	0	0.75	1	0.5	0.5	0
Case 23	0	1	0	0	0	0.75	1	0	0.5	0.5	0
Case 24	0	0	1	0	1	0	1	1	0.25	1	0
Case 25	0	0	1	0.5	0.25	1	0	0	0.25	0.75	1
Case 26	0	0	1	0	0.25	0.25	1	0	0.75	0.75	0
Case 27	0	0	1	0.5	0.25	0	0	1	0	1	0
Case 28	0	0	1	0.25	0.25	1	0	1	0.5	0.75	0
Case 29	0	0	1	0.25	0	0.25	0	0	0.25	1	0
Case 30	0	0	1	0.25	0.25	0.5	0	0.5	1	0.75	1
Case 31	1	0	0	0.25	0.25	0.75	0	0	0	0.5	1
Case 32	1	0	0	0.75	0.25	0.5	0.5	0	0.75	0.75	1
Case 33	1	0	0	0	0.25	0.75	0.25	0	0.5	0.5	1
Case 34	1	0	0	1	0.25	0.75	1	0.5	0.5	0.75	0
Case 35	1	0	0	0.5	0.25	0	1	0.75	1	0.75	0
Case 36	1	0	0	0.25	0.25	0.25	0	0	0.25	0.75	0
Case 37	1	0	0	0.75	0.25	0.25	1	0.5	0.25	0.75	1
Case 38	1	0	0	0.75	1	0	1	0.5	1	0.75	0
Case 39	1	0	0	1	1	0	1	0	0.75	0.75	0
Case 40	1	0	0	0.5	0.5	0	0.25	0	0.5	1	0
Case 41	1	0	0	0.75	0.25	0.25	0.75	0	0.75	0.5	1

Table 6. Crisp set membership for positive conditions

	Persistor	Questioner	Departer	StrongAdvisorRelation	GoodQualofLife	ClearGoal	LikesResearch	PosAcaEnvironment	StrongAcaSupport	StrongSocialSupport	NoCosts
Case 1	0	1	0	1	1	1	1	1	1	1	0
Case 2	0	1	0	1	1	0	1	0	1	1	0
Case 3	0	1	0	1	1	1	1	0	1	1	1
Case 4	0	1	0	1	1	1	1	1	1	1	1
Case 5	0	1	0	1	1	1	1	0	1	1	0
Case 6	0	1	0	1	0	1	1	0	1	1	0
Case 7	0	1	0	1	1	1	0	1	1	1	0
Case 8	0	1	0	1	1	1	1	1	1	1	0
Case 9	0	1	0	1	1	1	1	0	0	1	1
Case 10	0	1	0	1	1	0	1	0	1	1	0
Case 11	0	1	0	1	1	1	1	0	1	1	0
Case 12	0	1	0	1	0	0	1	1	1	1	0
Case 13	0	1	0	1	0	0	1	1	1	1	0
Case 14	0	1	0	1	1	1	0	0	1	1	0
Case 15	0	1	0	1	1	0	1	1	1	1	1
Case 16	0	1	0	1	1	1	1	0	1	1	1
Case 17	0	1	0	0	0	1	1	0	1	1	1
Case 18	0	1	0	1	1	1	1	1	1	1	0
Case 19	0	1	0	0	1	1	1	1	1	1	1
Case 20	0	1	0	1	1	1	1	1	1	1	0
Case 21	0	1	0	1	1	1	1	1	1	1	1
Case 22	0	1	0	0	1	0	1	1	1	1	0
Case 23	0	1	0	0	0	1	1	0	1	1	0
Case 24	0	0	1	0	1	0	1	1	1	1	0
Case 25	0	0	1	1	1	1	0	0	1	1	1
Case 26	0	0	1	0	1	1	1	0	1	1	0
Case 27	0	0	1	1	1	0	0	1	0	1	0
Case 28	0	0	1	1	1	1	0	1	1	1	0
Case 29	0	0	1	1	0	1	0	0	1	1	0
Case 30	0	0	1	1	1	1	0	1	1	1	1
Case 31	1	0	0	1	1	1	0	0	0	1	1
Case 32	1	0	0	1	1	1	1	0	1	1	1
Case 33	1	0	0	0	1	1	1	0	1	1	1
Case 34	1	0	0	1	1	1	1	1	1	1	0
Case 35	1	0	0	1	1	0	1	1	1	1	0
Case 36	1	0	0	1	1	1	0	0	1	1	0
Case 37	1	0	0	1	1	1	1	1	1	1	1
Case 38	1	0	0	1	1	0	1	1	1	1	0
Case 39	1	0	0	1	1	0	1	0	1	1	0
Case 40	1	0	0	1	1	0	1	0	1	1	0
Case 41	1	0	0	1	1	1	1	0	1	1	1

QCA facilitates two types of results reporting. For both crisp-set and fuzzy-set, necessity is indicated if the membership scores for a condition or configuration are consistently equal to or higher than the membership scores for the outcome. A relation of necessity indicates that a condition or causal configuration is required to produce the outcome and is reported by an assigned consistency score. This score allows the researcher to understand the extent to which a condition or configuration is consistently required to produce the observed outcome. In order to confidently conclude necessity, it is common practice to set the minimum acceptable consistency to 0.9. A score of 0.9 or above indicates that a configuration is a strong subset of the outcome (Ragin, 2018).

The sufficiency of a configuration to produce a given outcome can also be determined by observing the reported consistency scores. If the membership scores for a condition or configuration are consistently equal to or lower than the membership scores for the outcome, a relation of sufficiency is indicated. Sufficiency suggests that a configuration is a subset of the outcome, but will not always give way to the outcome. Consistency scores are again used to assess the sufficiency of a configuration for a given outcome.

Truth table analysis provided in the fsQCA software can best be used to identify both necessary and sufficient configurations. Truth tables present all possible, logical configurations in accordance with the observed outcome. It is important to note that while truth tables report all possible, logical configurations to the number 2^K configurations where K is the number of conditions included in the analysis, not all configurations reported are found in the cases. Such

configurations found to not exist in empirical data are referred to as remainders and are excluded from further observation.

In addition to reporting the consistency scores necessarily to determine causal configurations of necessity and sufficiency, fsQCA additionally reports coverage scores. Coverage scores indicate the degree to which configurations account for occurrences of a particular outcome. These scores are of particular use when there are multiple causal configurations indicating sufficiency. Coverage scores can then be used to determine the significance of each configuration.

Subset/Superset Analysis

When considering all eight conditions, it was found that the experiences of engineering graduate participants, simplified into configurations of conditions, was incredibly varied. Truth table analysis revealed that no more than two students were found to have the same causal configuration that presented strong sufficiency for the same outcome.

In order to identify trends in the experiences of participants that contributed to the outcome they experienced, subset/superset analysis was used prior to generating truth tables. Subset/superset analysis allows the researcher to identify all causal configurations and the consistency scores for each causal configuration. The causal configurations generated in subset/superset analysis present all possible causal configurations beginning with those that include only one condition through the configurations that include all eight conditions. When a condition is excluded from a causal configuration, its membership or non-membership is not implied. Rather, such a configuration does not consider the membership of the excluded

conditions. For example, given a causal configuration of poor advisor relationship*dislike of research*poor academic support, membership of negative academic environment, lack of a clear goal, poor social support, poor quality of life, and cost is not considered and cannot be determined simply from the presentation of the causal configuration.

Pathways to Questioning

Using the fsQCA software to run analysis on the crisp set data resulted in no indication of sufficient pathways which led participants to consider leaving their program. A threshold consistency of 0.75 was selected as a determinant of sufficiency. Consistency scores below this indicated too much inconsistency in outcome to reliably be used to draw any conclusions. Using subset/superset analysis, configurations with consistencies greater than or equal to 0.75 were identified, producing a list of five causal configurations. These configurations were each utilized in further truth table analysis in an attempt to highlight common experiences that were sufficient for questioning. While truth table analysis did produce multiple configurations with consistencies greater than or equal to the threshold, these configurations were common across no more than four students indicating that the experience was not widely shared across many participants, as shown in Table 7. The total number of participants identified as “questioners” in the study is 23.

Table 7. Crisp set causal configurations for questioners

Poor Quality of Life	Lack of Clear Goal	Cost	Negative Advisor Relationship	Negative Academic Environment	Number	Consistency
1	0	x	x	x	4	0.75
1	1	x	x	x	2	1
1	1	1	x	x	2	1
1	0	0	x	x	1	1
0	1	0	x	x	1	1
1	x	x	0	x	4	0.75
1	x	x	1	x	2	1
1	x	x	1	1	2	1
1	x	x	0	0	2	1
1	x	1	0	x	4	0.75
1	x	0	1	x	1	1
1	x	0	1	x	1	1

Using fuzzy set data provides a clearer picture of common pathway(s) that led participants to consider leaving their program. The same consistency threshold was used, producing two causal configurations for further analysis using truth tables. The truth table is presented in Table 8.

Table 8. Fuzzy set causal configurations for questioners

Negative Advisor Relationship	Negative Academic Environment	Lack of Academic Support	Cost	Number	Consistency
0	**1**	**0**	**1**	**5**	**0.8**
1	1	1	1	4	0.75
1	0	0	0	2	1
0	0	0	0	1	1
x	1	1	1	4	0.75
x	0	0	0	3	1

Only one causal configuration was determined to meet both the number and consistency thresholds to be considered substantive to produce final solutions. While fsQCA produce three types of final solutions – the complex solution, the parsimonious solution, and the intermediate

solution – the intermediate solution is considered to have the highest level of interpretability and to be the most useful by Ragin (Ragin, 2018). The intermediate solution resulting from the analysis of the four conditions revealed ~negative advisor relationship*negative academic environment* ~lack of academic support*cost to be a sufficient causal combination for questioning. Note here that a condition proceeded by "~" indicates the negation of that condition in the experience of participants. For example, "~ negative advisor relationship" indicates that participants did not experience a negative relationship with their advisor. It does not, however, imply that their relationship was wholly positive due to the method in which membership was assigned for some conditions in this study.

It is interesting to note that when the data for men and women was analyzed separately, the causal configurations sufficient for questioning differed both from the overall causal configuration as well between men and women which can be seen in Table 9. While a negative academic environment contributed to consideration of departure across the board, sufficiency for men was reached when pairing this condition with a dislike of research and cost in contrast with the causal configurations for women which paired a negative academic environment with poor quality of life and cost or singularly with a lack of academic support.

Table 9. Differing causal configurations for men and women questioners

Causal Configuration	Number	Consistency
Men		
Dislike of Research*Negative Academic Environment*Cost	5	0.8
Women		
Poor Quality of Life* Negative Academic Environment*Cost	6	0.83
Negative Academic Environment*Lack of Academic Support	6	0.83

For the data that was group by other demographics, there was not enough participant data for the outcome of questioning to determine sufficient causal conditions.

Pathways to Persistence

Similar to the results for questioning, no causal configurations sufficient for persistence were able to be determined using crisp set QCA. Causal configurations produced using subset/superset analysis and truth tables indicated that causal configurations with consistencies above the threshold applied to the experience of only a single student. Additionally, causal configurations that were represented in a large number among the participants contained too much variance in outcome to strongly be considered a subset of the persistence outcome.

Results obtained from using fuzzy set also indicate that the experiences of participants persisting in their program are varied. Among the causal configurations obtained from fuzzy set analysis, there were no configurations that had a reported consistency above the threshold consistency value of 0.75. Intermediate solutions for persistence were obtained using causal conditions with consistency values closest to the threshold given that these configurations represented at least three of the eleven cases of persistence. The solutions are presented in Table 10. It is important to note, therefore, that any statement about the sufficiency of the following causal conditions for the pathway to persistence must be taken with a decreased level of confidence.

Table 10. Fuzzy set causal configurations for persisters

Causal Configuration	Number	Consistency
Poor Quality of Life*Lack of Clear Goal*Negative Academic Environment* Lack of Academic Support	3	0.67
~Poor Quality of Life*Lack of Clear Goal*Negative Academic Environment*~Lack of Academic Support	3	0.67

It is interesting to notice the both the presence and negation of poor quality of life and lack of academic support among the intermediate solutions. Likewise, it is especially counterintuitive that students experiencing low levels of support and those who enter graduate school without a clear goal are among those who commonly persist. Such interesting points are discussed in the following chapter following connecting causal conditions back to the original interviews.

For persisters, causal configurations were also determined for the positive valence membership evaluation. The configurations that result represent the conditions that, when experienced in a positive light, aided in encouraging participants to remain in their programs despite the challenges that they were facing which were pushing them toward departure.

Like the results for the negative experiences, the causal configurations for the positive experiences indicate that the experiences of persisters vary greatly and no sufficient causal conditions were found. In this case, the crisp set data provided the causal condition with the consistency closest to that of the threshold of 0.75. As experienced by six students, the intermediate solution of strong advisor relationship *good quality of life * ~clear goal * likes research * strong academic support * strong social support * ~cost was the strongest causal configuration with a consistency of 0.67, which is near sufficiency. Here, it is worth noting that this configuration includes all of the conditions except for positive academic environment.

Pathways to Departure

Of the 41 study participants, seven were identified as having departed from their program, representing a smaller pool of data than for the outcomes of questioning or persistence.

Therefore, when analyzing the departure data, configurations which were experienced by a smaller number of students than before were considered as being significant.

Crisp set data indicated one casual configuration sufficient for departure. A casual configuration of ~poor quality of life*dislike of research*~negative academic environment was deemed sufficient for departure with a consistency score of 0.75. Four participants are identified to represent this configuration. It is noted, however, that the configuration indicates the presence of only one condition along with the negation of two additional conditions. Regardless, it is significant to note that four out of seven departing students experienced some difficulty with research during their graduate studies that contributed significantly to their decision to discontinue their studies.

Interestingly, analysis of the fuzzy set data did not produce any causal configurations which were sufficient for departure. The causal configurations produced contained significant variation in pointing toward a particular outcome with the highest consistency score reported being 0.50. As a result of such low consistency scores, not even careful statements can be made regarding the sufficiency of causal configurations to form a pathway to a particular outcome. Such results may point to the presence of a singular, significant incident which pushed participants to depart from their graduate program.

Chapter 4

Supporting Qualitative Evidence for Causal Configurations

In this analysis study, the experiences of engineering graduate students were examined as combinations of conditions and configurations that were linked to each of the three student outcomes – questioning, departure, and persistence. Ultimately, this research supported the claim that the experiences of graduate engineering students are highly varied and there is no one pathway that can be identified to ensure a student proceeds successfully through his or her program to graduation, nor one pathway that guarantees a student will depart from their program. In identifying causal configurations that were sufficient to lead to questioning, departure, or persistence, the number of students who shared the same causal configuration and outcome did not exceed six students, illustrating just how varied the experiences of the study participants were.

However, the primary research questions for this study aimed at identifying causal configurations that were sufficient for each of the outcomes, which were successfully identified using intermediate solutions generated through QCA. Questioning is linked to a negative academic environment paired with high perception of the costs of graduate education as well as the negation of both a negative advisor relationship and lack of academic support. Assessment of differences between causal configurations which led men and women to consider departure revealed that dislike of research, when paired with a negative academic environment and cost perceptions, influenced men, while women were pushed toward questioning by experiences of poor quality of life as well as a lack of academic support when paired with both a negative academic environment and cost, or just the former. Identified pathways to persistence contained a high degree of inconsistency, but are presented nonetheless. Persistence was most commonly

observed in the presence of a poor quality of life, the lack of a clear goal, a negative academic environment, and a lack of academic support. The same is also true of a configuration including the same conditions, but with the negation of a poor quality of life and the lack of academic support. Sufficiency for departure was created from a combination of dislike of research with the negation of a poor quality of life and a negative academic environment. Contained within each of the presented sufficient configurations are multiple conditions of particular interest due to their contradiction to expectations or support of existing research, which will now be explored.

Academic Environment and Cost for Questioners

When analyzing questioners, two negative experiences rose as strong contributors to participants' questioning of whether or not to remain in their graduate engineering program. An overall unfavorable academic environment made it hard for students to imagine that they could endure the entire duration of their program and perceptions of costs led students to envision more favorable lifestyles.

Participants shared a variety of grievances surrounding their academic environment and how it contributed to an overall negative perception of their life in graduate school. Some of the most prominent contributors to negative environments, as shared by participants, included a lack of community, high levels of pressure, a loss of individuality, and damaging interactions with faculty and peers. One participant even referred to the graduate school environment as the "Wild West." Many of these factors, which dictated the environment of graduate school, surrounded participants on a daily basis, giving them little reprieve from a world in which they felt they were constantly being torn down rather than built up. Students were led to question how much more

they could withstand. Those who were able to best cope with their environment were students who were able to unite with peers in their collective suffering or to seek out personal support in other places, which diffused their inward distress.

> *I don't think that any of us would still be in the lab if we didn't have each other. And that's a common conversation that we have with each other, is like, if we didn't have each other and all that we had was this toxic work environment, I think any of us would rather start over somewhere else, or go into a different field, because it's... You're in your PhD for so long, and there isn't really a clear time frame and just committing to that kind of unknown toxicity for so long is intimidating.*
>
> — *Isabelle*

For most participants, cost did not refer to any financial burden placed on them. Indeed, most engineering graduate students receive funding for their graduate studies which removes that burden which students in other disciplines might face. If a participant did feel that they were experiencing some sort of financial cost that caused them distress, it was most commonly an opportunity cost which was derived from an understanding that they could be making significantly more money if they were working in industry. Other perceived costs included mental and emotional costs, the toll which graduate school took on relationships, and the cost of having to deviate from an idealized life timeline which included benchmarks like owning one's dream home, getting married, and having kids.

> *Not getting to live in the geographic locations that I wanna live in. That's been a big one for me because you're so limited by certain areas. I definitely do think that, yeah, I could have gone to industry and gotten a job and earned more money, or I could have focused more on my personal life and today, maybe I'd be in a serious relationship, or I'd be*

engaged or I'd be married or something like that. And it kind of pushes back a lot of these other milestones that you have in your personal life.

— *Yara*

However, the extent to which participants were afflicted by struggles within their environment or considerations of the personal and professional costs taken on by committing to pursuing a Ph.D. was not enough to convince them to terminate from their degree program. For many, other factors encouraged them to forge forward including supportive advisors and unwavering determination to achieve the goals they had set out to fulfill by getting a Ph.D.

Differences in Men and Women Questioners

While the sufficient configurations of men and women questioners, when analyzed separately, strongly related back to the sufficient configuration of all questioners, multiple additional conditions appeared which both differentiated men and women from each other as well as from the trends observed among the entire group. For men, a dislike of research appeared alongside adverse feelings toward academic environments and struggles with costs. For women, a poor quality of life along with a negative academic environment and the perception of hefty figurative costs frequently led to consideration of departure as well as the combination of a negative academic environment with a lack of academic support.

For men, the emphasis on research may be due to the importance men place on making progress to show achievement. Many of the men who experienced frustrations with research cited that they struggled most, not because they could not connect with their research topic, but rather that they had lost a sense of direction on where the project was going or they were not

making progress that was satisfactory in their own opinion. In a field that is male dominated, men are less likely to feel incapable and it is probable that many of the male participants never felt unqualified during their undergraduate years. Upon encountering roadblocks which seemed insurmountable, new feelings of incompetence arose, leaving men more frustrated and wondering where to go from there. Often, their first instinct was not to ask for help, but to continue searching for the answers themselves. Students who were able to overcome their pride and ask for help found more satisfaction in moving forward in their research.

> *So this is one thing that I've struggled with my whole life... And I think a lot of people at our level do... Which is seeking out help. So when you're stuck, just even getting the courage to pick up the phone or write that email saying, "I'm stuck on this part, can you help me out?" And I'm not sure that that's something just about me so much as it is people who get to the level that we're at. Because on some level, you can't get to the level we're at without being a persevere person, a perseverer, sorry. And it's hard to break that, it's really hard to break that, when you reach a wall or a road block. Sometimes if you just ask advice, "Hey, I'm stuck here, can you meet me," and he said, "Sure," and he'll tell you what you're doing wrong in five seconds. I can't tell you how many times that's happened to me, but it's being willing and able to reach for that help that's really offered.*
>
> — *Joshua*

In this study poor quality of life was characterized by mental health, work-life balance, and a sense of belonging. Research supports that women both tend to experience more mental health related struggles and are more open to talking about them (Mackenzie et al., 2006) In the context of this study, this is significant because not only are more women likely facing mental

health problems, but the men who are also experiencing those same problems are statistically less likely to have mentioned them in the interview. Many female participants cited seeking out professional help for anxiety and overwhelming imposter syndrome. Additionally, navigating belonging has long been a struggle among women in engineering. In a field in which they are the minority, it can be difficult for women to feel at home, again contributing to the widespread experiences of imposter syndrome. Even in the face of anxiety, imposter syndrome, or feelings of not belonging, some women were able to take a step back and put things into perspective, which strongly aided in their perception of their current position.

> *I have talked to some people about it, and kind of just remembering where I am in context of my PhD journey is really important, because I've only been doing research for two and a half months. It's okay to not have my first paper, or even have a proper research direction. So I think keeping all that in check is good, 'cause it's hard not to compare yourself to people who are two years older than you, who have eight papers and then you're like, "Oh shit." But yeah, I just remember that it's my path and it doesn't have to look like other people's.*
>
> — *Daisy*

For women, multiple sources of support and good relationships assist in higher rates of persistence, so it is no surprise that a lack of academic support arose as a supporting condition for women considering departure. In addition, there has been a rise in programming across colleges and universities to offer support to women, especially undergraduates, pursuing engineering degrees as the importance of retaining women in engineering fields has been recognized. These opportunities give young women mentors to engage with and look up to. Having grown accustomed to being highly invested in, women may struggle when facing

unsupportive relationships with advisors or feelings as though the issues they present to their departments are ignored.

> *As a group, we all experience these things and we kind of shout about what works well and what doesn't work well, and they have not gone well, in terms of like, hey, I need more support from you and her basically being like this is my advising style, and if it doesn't work for you, I don't know what to tell you.*
>
> — *Eliana*

While configurations that are sufficient for consideration of departure differ for men and women, ultimately their roadblocks point to one need across the board. Graduate engineering students need people who they can turn to in the midst of tough situations whether it is with research, mental health, loneliness, or feeling unsupported.

Lack of Support in Persisters

Contained in both of the prominent configurations which suggested common pathways to persistence, lack of academic support was highlighted as a reoccurring condition both in its presence and its negation. Both the presence of lack of academic support in among persisting students and the contradiction of this with its negation are interesting.

Upon returning to the transcripts of participant interviews, it became clearer why students were able to persist even when they felt unsupported academically. Often, students who identified that they experienced insufficient support academically, whether that be from an advisor, department, or university as a whole, found that they were able to form a strong network of social support which was able to counteract where academic support was lacking. Students

who were able to place an emphasis on the abundance of support from peers, friends, and partners, rather than excessively dwell on the areas in which support was absent or lacking, were better able to cope with the challenges that came with the inability to find strong support systems within their academic life. Among participants who identified as persisters and indicated that they felt a lack of academic support, all of these participants also indicated that they felt that they were well supported socially.

For persisting students in which the lack of academic support was negated, a different view on support developed. These participants expressed resignation to the status quo. In this sense they never expected that they should receive an exceptional or even satisfactory level of support. Rather than becoming discouraged or feeling neglected as a result of feeling unsupported, students were able to continue on in their graduate studies because their expectations were met. They never expected to be supported well and therefore could not feel dismayed in the same way students who expected high levels of support might feel.

> *I definitely believe in the stereotype that engineers in general aren't people persons. They don't really have as much social skills which I definitely have met plenty of people that are just amazing speakers and amazing at giving advice but in general, an engineer is probably the last person I would go to for emotional support if I needed it and just because of the stereotype but I definitely believe it's like a true thing and so the department at my institution, they have town hall meetings, within the Chem E department but that's really just to discuss potential issues that graduate students wanna bring up but it's nothing like emotional support, I would think.*
>
> — *Ignatius*

Alternative to either seeking out support in other places or feeling indifference to the absence of support, there was another group of participants who found a new sense of motivation in the midst of their challenges with support. This group of students recognized the ways in which their expectations for support were not being met and how this inhibited them in their graduate studies. They then became resolved to incite change so that they might shift the culture of support for graduate students who come after them. Whether through engaging in graduate councils or petitioning for change, these students felt that they could do the most regarding their own situation by ensuring that the problem would not propagate through additional generations of graduate students.

> *Yeah, I mean, so right now me and some of my friends are like, we're trying to do things to improve that. One thing that we're doing, and I don't know if this is going to help at all, but we we're trying to get signatures on a petition to have faculty attend, um, sensitivity training. Like basically, um, like being more aware of how they're interacting with their students. I think, um, I think, I think like, I mean, a big thing would just be having the advisers take management training, right.*
>
> — *Alice*

Regardless of a student's expectations for academic support, nearly all students acknowledged that increased support in their academic life would ultimately improve their experiences as a graduate student. Many participates expounded on what good academic support would look like for them and for many, it came down to basic sentiments of support such as simply having people who they knew they could rely on when they were facing hurdles.

Just being able to reach out and finding someone that's willing to listen or willing to help out. Yeah, I guess that's about it. It's just like not feeling afraid to reach out or knowing how to reach out.

— *Laura*

Lack of Clear Goal in Persisters

It was also interesting to find that students who lacked a clear goal for pursuing graduate studies were often those who were able to persist despite facing multitudes of challenges. It would be otherwise expected that without a clear sense of an end goal, students would more easily become unmotivated and deviate from their studies when hurdles arose.

An especially strong theme which was found among persisters upon returning to the interviews was the role of identity rooted in underrepresented groups. Many of the participants who were identified as persisters without a clear goal were women and many were women of color. These students derived a sense of motivation to forge on even when things got tough because they viewed themselves as a representative for women and women of color stepping into the traditionally white-male dominated field of engineering. Oftentimes, they felt they had a need to prove themselves in a world that told them that women couldn’t and shouldn’t pursue advanced degrees in engineering. Students from diverse groups often feel a responsibility to change the statistics and forge paths for those who come after them, and while it can be acknowledged that their effort is important in accomplishing greater diversity within engineering, we also must acknowledge the additional burden placed on students and work to support them and help them do the important work in the best ways possible.

> *I've wanted to stay because, in terms of academia, there was only one woman of color faculty in our entire school of engineering, which I forget the number, how many that is, so I kind of... For the same reason, "If not me, then who? And I remember my best friend, she told me, she said, "You're the professor I wish we had."*
>
> — *Sasha*

In the same vein, while many of these women entered graduate school without a clear vision of the future they were working toward, the experiences surrounding being a woman in engineering helped them to develop a sense of purpose. They were able to reflect on their experiences both at the undergraduate level and at the graduate level to identify how their academic experience would have been different had they had strong female mentors to look up to. Subsequently, these women took on mentorship roles for younger students and found a great sense of purpose in being able to serve as role models for other students. Some even began to develop a clearer career goal as a result.

> *But at the beginning, when I started getting a lot of experience with teaching and mentoring and interacting with students and educating them, I started to shift my goals into really wanting to teach, but not necessarily wanting to do research. But not necessarily wanting to be a professor. So then I was trying to figure out how to craft so I could still be an engineer in the way that I define it, still doing engineering work but teaching. And then, I don't know, at some point it just seems like, "Oh well, I'll just be a teaching professor." That way I'm... I don't know. I don't have to worry about research and then I can just teach and that sounds delightful.*
>
> — *Athena*

While it may be concerning to hear students express that their primary motivation for entering graduate school is to give themselves more time to figure out what they want to do, from the narratives of participants in this study, the result is not always departure. Especially for students in underrepresented groups in engineering, they may find their purpose along the way.

Research for Departers

A dislike of research formed the crux of negative experiences that pushed students to depart from graduate school. To form a configuration sufficient for departure, a dislike of research was paired only with the negation of two other conditions: a poor quality of life and a negative academic environment. A graduate student's research and dissertation is acknowledged as the work central to their education, so it is no surprise that a student struggling with research would feel compelled to depart from their program.

The first challenge that participants indicated that they faced in their research was a lack of interest in the research topic they were pursuing. In some cases, a misalignment of the research interests of the student with the research they were directly working on was a direct result of a lack of transparency. Some students lamented over advisors who had intrigued them with research explanations prior to joining a lab, only to find that the projects which they were placed on upon joining the lab were completely different than what was explained. Other participants found that while they had an interest in the overarching discipline in which they found themselves, the specific project which they were placed on failed to interest them.

I came in, my advisor told me... He kinda like described a project to make it, I think, more interesting to me. And then when I got here the project isn't really related to what he

described to me. I thought I'd be working more with...And so I thought that I'd be more involved with coastal processes, and in the environment, and you know looking at these marshes, when I'm not at all.

— *Heidi*

A second challenge arose when participants found that they constantly felt disoriented by the research process. Students expressed feelings of uneasiness when conducting research because they didn't know if they were "doing the right thing." Being given autonomy over their projects conjured up overwhelming anxiety rather than making students feel empowered to explore. Seemingly trained by prior education that there must be a right and wrong answer, these students struggled most when they failed to grasp the future direction of the project or when a lack of visible progress became intensely frustrating.

I could very easily press the wrong button, completely screw my results, and not have any idea for six months, and not even in a publishable way, it's like, oh, I screwed this up, I failed to take this variable into account, and I have no idea until the data comes through, or the data could come through, not show anything, and I look at it, I'm like, well, I have no idea. Did I... Is it supposed to look as bad, or not? Did I screw something up? Or is this just a set-up issue? So it just felt like things were very uncontrolled and I had very little way of knowing if I was doing the right thing.

— *Francisco*

As such a large component of a graduate student's life, research proved to have a large impact on participants' decision to terminate their degree. Problems were further exacerbated when students felt trapped in their current research position either because of ties to funding or the inability to switch labs within their department. Despite a trend in more positive academic

environments and satisfactory quality of life, participants who ultimately departed were strongly influenced by their relationship with their research.

Chapter 5

Discussion and Conclusions

This study builds upon earlier work which explored individual factors that influenced engineering graduate students' questioning of or decision to depart from their graduate programs (Ampaw & Jaeger, 2012; Berdanier et al., 2020; Cooke et al., 1995; Gardner, 2008; Lovitts, 1996; Spaulding & Rockinson-Szapkiw, 2012). However, this is the first study to explicitly identify links and interactions between multiple factors and the ways in which factors, acting together, often leads engineering graduate students down particular paths in regards to attrition outcomes. While an individual experience might break graduate students and wholly convince them to leave, more often than not, graduate students experience a conglomerate of adverse events that build on each other to develop feelings of not belonging, isolation, and overwhelming stress or anxiety which ultimately become too much for students to bear. The importance of the impact of such feelings has been acknowledged in prior literature (Gardner, 2008; White & Nonnamaker, 2011), but this study has also identified the experiences and environments that so often give way to the development of these feelings.

While this study was able to identify causal configurations, which exhibited trends in leading toward specific graduate student outcomes, it is necessary and important to realize that these configurations were not universal. There were still students who experienced the same or very similar experiential configurations who landed in difference outcomes. Engineering graduate school is innately experienced and perceived by each student in an individual way as a result of the many variables associated with each experience including student background,

advisor pairing, life outside of school, location, and goals. It is, therefore, imperative that we treat engineering graduate students, on the whole, not as a generalizable group, but as individuals who interact with and perceive their lived experiences in personal ways.

One of the most practical takeaways from this study is that attrition cannot and will not be ameliorated simply by identifying the negative conditions that engineering graduate students experienced, which led to the adverse outcomes of questioning and departure, and by focusing on creating more positive experiences in those specific areas of graduate student life. Analysis of the positive conditions which persisters experienced, which aided them in continuing forward with their graduate education, indicates that the solution is not just the inverse of the causal configurations. The causal configuration derived from the positive conditions for persisters tells us that we need to be working toward developing strong advisor relationships, satisfaction with quality of life, support and encouragement in research that fosters passion, and strong academic and social support systems. This configuration included positive experiences in nearly all of the eight conditions recorded in this study set aside having a clear goal, perception of costs, and a positive academic environment which were indicated to be less essential to fostering persistence. Graduate students need to be support in having a well-rounded and well-supported academically oriented life. Yet, we should recognize that persistence should not entirely be the ultimate goal for the graduate student experience as persisting still indicates some level of struggle and overcoming what may be identified as unnecessary challenges.

Implications for Stakeholders

Implementing better practices to ensure the success of engineering graduate students and to reduce unnecessary attrition can begin before students even enter graduate programs. During the course of participant interviews, students reflected on their journey into graduate school and many shared experiences of sliding into graduate school rather than deciding to embark on the pursuit of additional education. Although undergraduate students cannot be forced to engage with faculty mentors or to get involved in activities, such as research, that would give them a better idea of what they would be getting into in graduate school, it is vital that these opportunities are made widely available, accessible, and easily integrated for undergraduate students. The opportunity to sit down with a faculty mentor and to flesh out passions and goals for the future could aid students in explicitly deciding if graduate school is the right path for them or if they can better achieve their dreams by heading in a different direction following graduation with their undergraduate degree. In addition, experiencing research at the undergraduate level prior to the graduate level would expose students to the challenges that come with pursuing research questions. Many participants in this study shared how the challenges they faced in research, such as lack of direction and not knowing if they were doing the "right" thing, heavily discouraged them and were not challenges they enjoyed tackling and growing from. Undergraduate students are widely exposed to various challenges in their coursework, but these differ dramatically from those faced with research. The ability to understand the potential challenges one might face in graduate research and to know if these are enjoyable challenges would be a valuable insight for students prior to deciding to go to graduate school.

For current engineering graduate students, it is most important to understand that they are not alone if they begin to question remaining in their program. In fact, the prospect of

questioning is more of a "when" than an "if." It is not an observation, but a fact that graduate school is difficult and presents a plethora of novel challenges which many students have never been exposed to. A level of reflection surrounding individual ability and desire to work through these challenges to achieve an ultimate goal is rather an essential part of ensuring that graduate education is propelling individuals toward their desired future. Questioning remaining in one's program does not betray an individual's ultimate goal and even departing should not be considered a personal failure if it is determined that students can achieve their goals without a graduate degree. Conversations surrounding personal feelings toward remaining in one's program are conversations that are imperative to have in order to help students know that they are not alone and that, rather, it is natural to question.

Throughout the course of this study, students expressed in various ways the adverse ways that a lack of transparency, expectations, and communication affected them. This is of particular importance for graduate student faculty and advisors to grab onto as an area in which they can make strides to better support their students. One practical way of implementing practices to alleviate these stresses would be for graduate students and their advisors to sit down on a scheduled basis, perhaps each semester, and to lay out explicit expectations, lines of communication, and needs to ensure success. One of the biggest challenges for engineering graduate students to overcome seems to be the misalignment between what they need and expect and what their advisors think that their students need and expect. Directly laying all of these things down so that both parties are on the same page would be an easy way to decrease additional problems in the future.

In addition, although not heavily explored in this study, many student narratives produced lived experiences dealing with both racism and sexism within their graduate departments which

heavily influenced their feelings toward belonging in their program and feeling welcome in their department. In this study, many of these sentiments were included in membership for how students experienced their academic environment which was proven to be highly influential in participants' outcomes. It is sadly realistic to acknowledge that racist and sexist sentiments are not going to be erased overnight, especially in the field of engineering which has been long dominated by white males. However, it is realistic to vigorously work to change the culture in engineering surrounding race and sex. Faculty and staff would benefit from additional training on how to foster better cultures in their labs and departments for all students regardless of race or sex. Most importantly, faculty and staff need to keep each other accountable and to encourage those uncomfortable conversations throughout their department, realizing that it will only better their university and its students. Given that this change will not be automatic, university departments should consider preparing students of traditionally underrepresented groups in engineering for what they might face. Students from these groups might find it beneficial to sit down with a faculty or staff member to discuss how they will handle situations in which they feel belittled because of their race or sex, prior to embarking on their graduate school journey. As not all advisors are equipped to have such strong conversations, it is highly advised that universities consider appointing or hiring specific faculty and staff members to have these conversations and to serve as points of contacts for students to trust and come back to when they do experience racism or sexism.

Conclusions

This study aimed to better understand the experiences of graduate engineering students as characterized by combinations of attrition factors and to identify which, if any, of these combinations were sufficient to lead to the outcomes of questioning, departing, or persisting. The narratives of N=41current or former engineering Ph.D. pursuing students were recorded and analyzed, providing data which was used in QCA in an attempt to produce causal combinations sufficient for each of the three outcomes.

While sufficient causal combinations were found for the outcomes, ultimately, the experiences of graduate engineering students are highly varied and there is no one pathway that can be identified to ensure a student proceeds successfully through his or her program to graduation nor one pathway that guarantees a student will depart from their program. Small groups of students followed similar paths to achieve the same outcome, which highlighted the importance of certain conditions on student outcomes. It is evident from this study that student outcomes in terms of attrition are the result of a multiple conditions acting together which ultimately push a student to decide how they wish to proceed in his or her academic life. When looking at the causal configurations presented in this study, we must also remember that participants often experienced additional conditions on top of those which are seen in the configurations which differentiated their experience and may have weighed on their individual decision in regards to their outcome. Whether to stay or leave is a decision that engineering graduate students make many times over as they encounter new experiences and challenges. It is interesting to note, however, that some students who noted experiencing the same or very similar combinations of conditions did not reach the same outcome. This may suggest that attrition has

ties to qualities which are innate to individual students and what they perceive as barriers unable to be overcome.

Overall, to move forward in improving the lives and experiences of engineering graduate students, we must work toward developing an understanding of how we can best aid students as they face various challenges during the course of their studies. While the needs of each student are largely individual, we can integrate better systems of support and more open lines of communication to take strides to improving higher education in engineering.

Future Work

The possibility to utilize QCA as a method of analyzing trends among graduate students and their experiences in future work has wide-ranging potential. While this study attempted to explore the differences in causal configurations for different demographics of students, the participant pool for varying demographics proved to be too small to produce causal configurations of sufficiency for any group besides men and women questioners. However, even in the exploration of just two demographic groups, we can see that there are differences in the conditions which influence outcomes for different groups of students. Recruiting for specific groups of graduate students in order to obtain a large enough study group is necessary to explore the causal conditions associated with each of these groups. Analyzing specific demographics of students will give insight into the particular challenges that they face that may deviate from that of the conglomerate body of graduate students as explored in this study and will give the engineering education community deeper insight as to what can be done to best support students in their journey through graduate school. The list of demographic splicing that could be

performed to derive unique causal configurations is extensive and includes ethnicity, years in graduate school, and background education. For example, it would be a compelling area of future work to examine trajectories and casual configurations for questioners who had attended historically black universities for their undergraduate degrees versus those who attended primarily white institutions. Given that this is the first study in engineering education to utilize QCA, this study paves a path to future exploration of engineering student narratives to determine causal configurations for particular outcomes.

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ACADEMIC VITA

EDUCATION

The Pennsylvania State University, Schreyer Honors College **Graduated: May 2021**
Bachelor of Science in Mechanical Engineering
Minor in Entrepreneurship and Innovation

WORK EXPERIENCE

Student Researcher, Engineering Cognitive Research Laboratory **May 2020-May 2021**
- Explore engineering graduate student attrition through analysis of personal narratives
- Utilize software to generate and predict future student outcomes

Project Management Intern, Burns Scalo Development **June 2020-August 2020**
- Communicated with architects, engineers, and subcontractors to ensure project timeline was met
- Assisted migrating company Development Department to new software to help manage projects

Teaching Intern, Penn State HESE **August 2019-August 2020**
- Connected with faculty and researchers to assist six social ventures in progressing toward launch
- Assisted program director with compiling resources and research to distribute to venture teams
- Engaged with student venture teams to provide guidance for the direction of social venture development

Safety Analysis Intern, Westinghouse Electric Company **May 2019-August 2019**
- Performed sensitivity analysis for steam generator modeling to determine impacts on the accuracy of steam generator transient events using a Westinghouse network code
- Authored a calculation note detailing the process and discoveries resulting from the sensitivity testing

ACTIVITIES

Humanitarian Engineering and Social Entrepreneurship (HESE) **August 2018-May 2019**
Lead Researcher
- Work with team members to launch a social venture that aims to improve inefficiencies in the Kenyan produce supply chain through a smartphone app
- Performed field research in Kenya with local partners and a developing customer base

Club Cross Country **August 2017-May 2021**
Executive Board, President **December 2019-December 2020**
- Lead team of 16 team leaders to effectively plan races, travel, training, and fundraisers for 200 runners
- Serve as primary contact to outside partners including Penn State Club Sports and the National Intercollegiate Running Club Association to ensure compliance with all rules and regulations

Executive Board, Secretary **November 2018-December 2019**
- Planned, organized, and communicated with executive board and teammates to maintain team success
- Collaborated with apparel companies to design and distribute team merchandise to 200 team members
- Managed team social media accounts to keep members engaged and informed with club events

Team THON Donor and Alumni Relations Chair **April 2018-April 2019**
- Engaged with current and alumni members to carry out fundraising and team involvement goals
- Led a $67k fundraising campaign to support families impacted by childhood cancer

HONORS AND AWARDS

Karidis Department Head's Award for Research Achievement in Mechanical Engineering	Feb. 2021
Dean's List	FA 2017-SP 2021
Penn State Supply Chain Pitch Competition, Third Place Team Award	Apr. 2019
Phillips Encouraging Women in Mechanical Engineering Award	Feb. 2019
Schreyer Honors College Academic Scholarship	2017-2021
Best Design Communication Award by People's Choice	Dec. 2017

PUBLICATIONS

M. Ellery, L. Hirpara, E. Akande, G. Schweiker, J. Gershenson, "Investigating Cash Flow in the Agricultural Supply Chain Within Kenya," IEEE Global Humanitarian Technology Conference (GHTC), Virtual, 2020, pp. 1-7.