How Satisfaction with Advisor Relationship Interacts and Evolves in Engineering Doctoral Students Questioning Whether to Leave the PhD

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***Abstract*— This research full paper presents a longitudinal multiple-methods project focused on the phenomenon of graduate attrition from the engineering PhD. There are relatively few investigations of graduate student attrition, and even fewer collect longitudinal and nationwide data representing dominant graduate student experiences. To this end, over the past several years, we have collected interview and longitudinal survey data from several large nationwide data collection efforts capturing data current students who are questioning leaving their PhD, many of whom decided to leave either with no degree or leaving with a Master's degree instead of a PhD. From these data, this paper investigates one critical aspect of attrition and persistence in doctoral education: the "advisor relationship." To this end, this paper answers the overarching research question: How do "questioning" doctoral engineering students' perceptions of their research advisors interact with other factors to promote attrition and persistence, and how do perceptions of relationships change over time? The data analyzed in this study includes nationwide interview data with N = 41 participants, and a longitudinal study of N = 113 doctoral engineering students who are considering whether to persist or depart. Data are analyzed using methods relatively new to engineering education research: Qualitative analysis was conducted using Qualitative Comparative Analysis (QCA), a method that quantifies qualitative data to understand the "causal configurations" of factors that lead to an outcome: In this case, questioning departure. We also employ a novel longitudinal SMS survey study, showing data collected over several years. Implications offer new perspectives to advisors, graduate chairs, and academic administrators who interface with graduate student issues, to work toward a more supportive environment in which graduate students can thrive. We show that advisor relationship is of significant importance, and that it is important to continue to attend to advisor relationship especially for late-stage graduate students.**

I. Introduction and Literature Review

Since doctoral attrition rates in engineering are lower than those from the humanities or social sciences[1], [2], most higher education researchers do not focus on engineering. Studies that do address engineering attrition often aggregate with science, technology, and mathematics [3], despite the variety of different graduate education structures of these fields compared to engineering. For example, Gardner [4] characterized the differences between low-, high-, fast-, and slow-completing programs: Engineering disciplines tend to be high- and fast-completing programs, with the average time to PhD degree completion being around 5 years, which is almost half the time to degree in some humanities programs. Another factor frequently cited as contributing to attrition are access to reliable funding [5]: However, in engineering, approximately 80% of students are fully funded through their PhDs, typically on research assistantships rather than teaching assistantships [6].

While earlier research focused on socialization in graduate school particularly with respect to the professorate[7]–[10], recently, scholars have begun taking closer disciplinary perspectives. There is a small but growing body of literature related to graduate-level engineering education related to transitions into graduate school [11], experiences in graduate school (e.g., [12], [13]); professional skills development of graduate students (e.g., [14]–[16]); and investigating discriminatory experiences of students from historically marginalized groups in engineering (e.g., [17]–[20]). Many of these studies confirm broader themes from higher education literature, such as the importance of the advisor relationship and mentorship [21], adding value in understanding the engineering context. As an intersection of several of these foci, one area of emergent interest is in studying attrition processes from the engineering doctorate[13], [22]–[25], as they concern motivation for pursing and continuing in graduate school, experiences during graduate school, and how the gendered and raced nature of academia and engineering influences how graduate students experience their education.

Nationwide studies of attrition are very rare. Quantitatively, the last comprehensive study of attrition, aside from those investigating particular minoritized groups (e.g., [2], [26]) was conducted in 2008 by the Council of Graduate Schools[1]—these studies are time intensive and require universities to parse through non-standardized definitions of attrition and persistence. There are also a variety of research limitations that lead to important gaps in the literature. Some attrition studies measure the “dropout intentions” of students who may or may not leave their programs [27], rather than capturing the experiences of students who are leaving or who have already left. Further, it is unclear in many studies whether students who

depart from the PhD with a Master's are "counted" in attrition statistics; surely, those narratives of those who leave the university are rarely captured or investigated.

Qualitative accounts of attrition typically separate factors for attrition by theme (e.g., Advisor relationship, (lack of) mentorship, financial security, belongingness, etc.) using small excerpts of interviews to support these themes[3], [28], [29]. Excerpted interview quotes from thematic research provide decontextualized evidence of specific themes, but often fail to show interactions between tensions. The graduate education literature in general lacks deep qualitative accounts of "the full story," in other words, how small events and experiences work together within a student's decision to leave. Instead, these "siloed" accounts of attrition imply that attrition is an instantaneous event, rather than a process that starts with "questioning." While most qualitative research accurately shows the predominant factors and themes that can cause students to consider departing, the narratives and stories from these participants are largely lost, and if they weren't lost, are highly identifiable, such that further reputational harm could come from sharing the details of the stories.

One of the most influential factors in whether a doctoral student persists or departs from their PhD is their relationship with their PhD advisor[30]–[32]. In engineering, different than in other social science or humanities domains, funding is tied from a funded project under and advisor to the graduate student, such that the advisor is expected to play both supervisory, advisory, and mentorship roles. Literature is clear that the advisor is critical, but it is less established how the advisor relationship may layer with other factors or may develop over time. To this end, the following paper asks the question: How do "questioning" doctoral engineering students' perceptions of their research advisors interact with other factors to promote attrition and persistence, and how do perceptions of relationships change over time?

II. Theory and Positionality

The theory that guides this work is the Graduate Attrition Decisions (GrAD) model for doctoral engineering attrition first presented by Berdanier et al. [33] and expanded by Sallai et al. [34], because it is the only framework that is engineering specific and focused on the attrition factors that particularly affect graduate engineering students. There are six dominant nodes: Goals, Cost, Quality of Life and Work (which includes mental health); Support Network; Perception by Others; and most salient to this work, Advisor. It is notable that in the original model, the advisor node is connected to nearly all the other nodes. The model was developed from a motivation perspective, specifically employing expectancy-value theory. While some aspects of this theoretical framing arise specifically in the model (e.g., the "Costs" node), the motivation framework implies that if and when the nodes erode, they also affect other factors that are related. It must be noted that the GrAD model was developed from qualitative data, and the links between the nodes were interpreted from qualitative narratives of decisions to persist or depart from engineering graduate programs, but quantitative approaches to investigate this layering paradigm will be an important value added to the model.

We as researchers conducting this study align with constructivist approaches to educational research, especially in accordance with attrition, which is a highly individualized process. Together the author team represents a suite of individuals from a variety of demographic backgrounds that were involved with data collection and analysis. Of note, the researchers conducting the interviews were graduate students, allowing ease of rapport and sharing. The student analyzing the QCA data was a senior level honors student at the time of the analysis, and the student collecting and analyzing the longitudinal survey data is a PhD student. We, including the PI, are trained in both engineering education research and mechanical engineering, and are situated in the mechanical engineering department at our university. This positioning gives us a very acute perspective of how attrition occurs in action and influences both our research decisions and the implications for stakeholders.

III. Methods

In this work, we use a sequential mixed methods approach to investigate this research question. This paper presents data from two data streams: An interview phase and a longitudinal survey phase. Both streams of data were collected as part of a larger funded and IRB-approved project on engineering doctoral attrition and comprise nationwide datasets; the specific data collection and analysis methods for each phase will be discussed in the following sections.

A. Qualitative Interview Data

Participants were recruited for this study by sending a recruitment email to graduate chairs and support staff in engineering programs at the top 50 engineering PhD-granting universities in the United States, identified as per the ASEE By the Numbers report in 2017, which is when this data collection phase began. Interested participants conducted an initial screening survey, which also served to understand broader trends. Participants indicated whether they would like to participate in a follow-up interview. From those interested, 41 interview participants were selected through stratified maximum variation sampling on the criteria of questioning status, gender, race, engineering discipline, and years in graduate school. From these participants, 23 identified as women, 16 as men, and 2 as non-binary or another gender. Six participants identified as Hispanic/Latinx; 2 as Black/African American; 4 as Asian, 33 as White, and 1 as another racial identity. 23 identified as actively questioning; 11 were persisters, and 7 as departers. Semi-structured interviews were conducted via Zoom with each participant, lasting between one and two hours. Interviews were transcribed by a professional transcription service to result in the transcripts which served as the dataset to be analyzed. Further methods are documented in other published work from this qualitative dataset [34-37] and the interview protocol can be obtained by contacting the first (corresponding) author.

Qualitative data can be analyzed in many different ways: To date, we have explored thematic analysis and narrative analysis through a variety of theoretical lenses to understand this rich

data set (e.g., [34-37]). However, for this paper, we are interested in understanding how factors layer together in ways that may not be initially evident, and to do this, we employ a method that is relatively novel for engineering education research, called Qualitative Comparative Analysis (QCA). QCA is a method suitable for moderate sample sizes (5-75 participants) in which qualitative data are quantified in ways that elicit relationships between themes. Promoted most noteworthily by Ragin [38], [39] and Rihoux [40], [41], QCA analysis is conducted by developing themes related to the phenomenon of interest, similar to content analysis, but then the researcher determines the extent to which each theme is present or absent in each participant. Crisp set QCA (cs-QCA) places presence or absence as a binary, whereas fuzzy-set QCA (fs-QCA) allows the researcher to interpret the degree to which the elements are present. These data are analyzed statistically using freeware to result in "truth tables" which are combinations of factors that can combine to result in a particular outcome: In our case, the consideration to depart from a PhD. From a constructivist standpoint, the attribute of truth tables is that they do not have to hold for all participants, but allows researchers to calculate the probability by which some combination of factors will result in the outcome of interest. In addition, it allows the analysis of larger numbers of qualitative interviews in ways that still promote a constructivist epistemology.

In our analysis, the factors that were analyzed corresponded with the nodes from the GrAD model for doctoral engineering attrition, as described in the theory section. In conversation with other members of the research team, one researcher coded all the data, determined the inclusion criteria, and loaded the data into COMPASSS (fsQCA freeware) [42] in order to analyze the data. Specifically applied to the research question of interest about advisor relationship, a crisp-set analysis would require the researcher to determine whether each participant's perception of their relationship with their advisor was "bad" (a binary score of zero) or "good" (a binary score of 1). Instead, we performed fs-QCA, and the researcher was allowed to interpret, guided by a standard judgement guide) the extent to which full membership was reached: For a participant that mentioned only attributes with negative valences, full membership was assigned and, inversely, those that mentioned only positive attributes were assigned full non-membership. For those in-between, "mostly-full membership" was assigned to cases where there were more negative than positive attributes discussed, "mostly non-membership" was assigned to cases were more positive than negative valences were recorded. Neutral membership was assigned to those cases were there were an equal number of positive and negative attributes discussed. The example of membership for advisor relationship are shown in Table 1. This decision allowed a much more nuanced appreciation of the impact of advisor relationship. The same methods of analysis were performed with the other GrAD model themes. For the purposes of this paper, which is particularly about questioners, only the data from the questioners will be presented.

TABLE I. FUZZY-SET QCA MEMEBERSHIP CRITERIA FOR THE CONDITION OF NEGATIVE ADVISOR RELATIONSHIP

Condition: Negative Advisor Relationship	
Full Membership (1)	Only negative advising characteristics mentioned or explicit statement of strong dissatisfaction with advisor relationship
Mostly Full Membership (0.75)	Disqualified for both full membership and full non-membership and mentioned more negative than positive advising characteristics
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 relationship

B. Longitudinal Quantitative Data

During the data analysis phases of the interview data, a second researcher worked to develop a short comprehensive survey that could be distributed via SMS text message survey several times per week. Methods to develop the survey are comprehensively discussed in prior work [43, 44] and included several rounds of pilot testing, cognitive interviews, and validity checking. To recruit participants for the longitudinal nationwide study, a recruitment survey was sent via email to graduate chairs and administrative staff in engineering departments at the top 50 PhD conferring institutions per the ASEE 2020 By the Numbers report. Similarly, the screening survey collected data to help the research team select which participants we would follow for a sustained period of time, on the factors of degree of questioning, gender, race, time in PhD, engineering discipline, and citizenship status. While we did collect data from a smaller set of international students, the experiences, motivations, and stressors of international students are substantially different than domestic students, such that we focus here on the experiences of US domestic students. For the first cohort of participants, which we focus on in this paper, 113 domestic students participated in the longitudinal survey from January 2022 to November 2023; over this time an additional 47 students left the study before study completion. Of these, 61 identified as women; 51 as men; 1 as another/non-binary. Nine students identified as Black/African American; 15 as Hispanic/Latinx; 21 as Multiple races; 25 as Asian; and 32 as White. Stage in graduate school was an important factor for analysis: 44 students were classified as early-career (in Y1 and 2 at the beginning of the study); 42 were mid-career (Y3 and 4) and 27 students were Year 5+.

Data collection occurred three times per week using an SMS text message survey sent to the participant's cell phones. Mondays, Wednesdays, and Fridays, the participants answered

two questions (scale of 1=strongly disagree to 7=strongly agree): Today, I am confident I will complete my degree objective and Today, the stress I feel is overwhelming. Each Friday, we asked questions related to significant events that happened, and more detail about stressors. At the end of each month, we collected data around satisfaction with advisors and other elements in the program, and at the end of each semester we asked broader questions about intentions to persist. Participants were compensated at the end of each month for consistent participation via Amazon.com gift card. The participants in the first cohort, with the exception of those who departed from their PhD during the study, were followed over the course of two calendar years. All these details are documented in prior literature. For the purposes of this paper, we will present data related to the advisor relationship perspectives. All data was downloaded into Excel and analyzed using Python to analyze trends over time.

C. Limitations

The data from this study were collected over time, in which there were several important global and national happenings. The interview data were collected between 2019 and 2020, and did overlap with the beginning stages of the Covid-19 pandemic. Participants engaged with the pandemic-specific stressors as needed in the interview protocol. The longitudinal data were collected between 2021 and 2023. Throughout this entire time, we cannot forget that graduate students are also living and working in a national mental health crisis, fueled by national economics, pandemic after-effects, and the "dual pandemic" of a rise of white nationalism and racism in the US, as noted by Coley and Thomas [45].

This study also focuses on U.S. domestic students, which is a limitation considering that over half of PhD students in engineering and computer science in the U.S. hold citizenship in another country. However, since the GrAD model was not developed with the stressors for international students, it would not be accurate or respectful to analyze their experiences through this lens. Work from our group is ongoing to understand international graduate student attrition considerations [46].

Last, these data were collected from participants located across the United States from those at the top engineering PhD-granting institutions. While the top 50 institutions comprise a majority of the conferred PhDs in engineering in the United States, we also acknowledge that these research-intensive universities are traditionally Predominately White Institutions (PWIs) and as such we do not capture the PhD experiences of students at R2 institutions or many minority-serving institutions.

IV. Findings

A. Qualitative Comparative Analysis: Causal configurations leading to questioning departure

Presentation of the full dataset for the Qualitative Comparative Analysis is too robust for a conference paper; for the purposes of this paper and these research questions, we focus solely on questioners. The causal configurations are selected in terms of researcher-defined sufficiency criterion and a consistency score, in accordance with methods literature. For the purposes of this analysis, we present the causal configurations that hit these thresholds; the consistency score of the configuration, and the number of participants for which this causal configuration held true. In order to dig into the data, we also present the data disaggregated by gender to understand whether there were any differences. Table 2 notes both the aggregate causal configuration and disaggregated by gender. To be clear, this is not a study or paper designed or intended to only investigate gender, but it is interesting to take note of potential trends for future work.

TABLE II. FS-QCA Causal Configurations for Questioners Considering Departure from the Enigneering PhD

	Causal Configuration	Number	Consistency
Questioners (N = 23)	Aggregate		
	~Advisor Relationship*Negative Academic Environment*~Lack of Academic Support*Cost	5	0.8
	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

Of note, the aggregate causal configurations highlight different configurations of factors that lead to questioning. As per the standard notation for QCA, the "~" sign before a factor means "absence of" and the asterisk (*) indicates the coupling of the factors with each other. Special consideration must be taken when interpreting the double negatives (e.g., "absence of lack of [a factor]"). In aggregate, the causal configuration with the strongest consistency score indicates that the lack of advisor relationship in concert with a negative academic environment and perception of costs, even with an otherwise strong support network most often leads to questioning departure.

Separating women and men, it is interesting to note the different elements that are even more important: Advisor relationship does not meet the thresholds to be included in the dominant causal configurations. However, it is noteworthy that for women, there are two dominant causal configurations that lead to questioning departure, involving quality of life, cost, and lack of academic support. For men, these aspects were not as salient, with dislike of research being more salient of a factor.

Taken together, these results indicate that advisor relationship is an important factor in considering departure across all students, but for different gender demographic groups, there are other aspects that are also at play that also contribute to satisfaction in graduate school and are incorporated in attrition decisions.

B. *Longitudinal SMS Survey Data Analysis: How Advisor Satisfaction Evolves Over Time*

In addition to understanding how the advisor relationship interacts with other factors in determining attrition decisions, we are also interested in how students at different stages perceive their satisfaction with their advisor relationship over time, as measured by our longitudinal SMS survey. The specific question we are presenting in this work is one of our weekly survey items, collected each Friday: "This week, I am satisfied with the relationship with my advisor" as show in Figure 1.

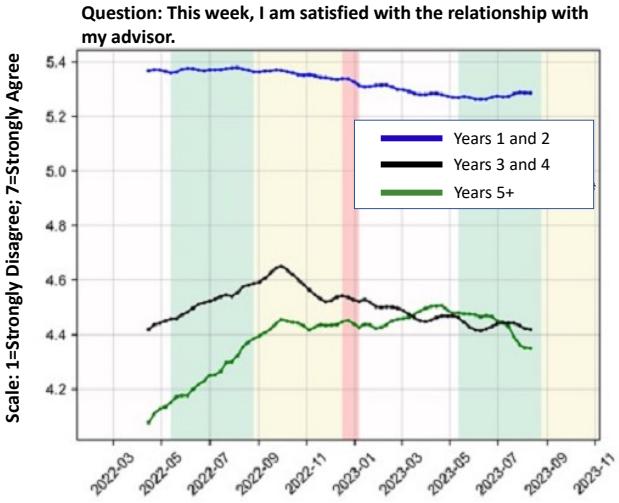

FIGURE 1: LONGITUDINAL DATA SHOWING PERCEPTION OF ADVISOR RELATIONSHIP OVER TIME

In this figure, we document the semester breakdowns in order to understand the data in terms of an academic timeline, with the white background being Spring Semester, the green being Summer Semester, and Yellow being Fall. The red background is typical winter break to note that seasonality. The average aggregate scores of the three stages of graduate student participants are noted on the plot. It is notable that the early-career graduate students scored consistently more strongly in terms of their perceptions of their research advisors, and the perception of the advisor relationship became more negative for the mid-career graduate students and yet more negative for the late-stage PhD students.

Over time, while some fluctuation does occur, the trend is overwhelmingly downward for each group of students, indicating that students lose positive perceptions of advisor relationships. Though these data are intended to be descriptive rather than prescriptive or predictive, the trends indicate that graduate students regardless of stage experience a decrease in advisor satisfaction. The scaling of the figure should be discussed: While the low average scores are still in the mid 4's out of 7, they are still lower than the early career graduate students. Given that there were 27 late-stage doctoral students in the sample, an average of a mid-4 indicates that many were well below that value.

V. DISCUSSION, IMPLICATIONS, AND CONCLUSIONS

The purpose of this paper was to answer questions related to how "advisor relationship" as a common narrative interacts with other factors to affect attrition, and how it develops over time. The QCA results show in sum that the advisor relationship, while an important part of an individual's decision to persist, is not the only thing that causes attrition, and that chances that an individual considers attrition are higher when coupled with other factors, particularly other support network factors. In addition, by performing the QCA in reverse for persistence, we see that while the combination of only a few factors leads to an increased chance of departure, to support persistence, there must be more representation of positive presence of more of the factors. This finding holds significant implications for the advising, mentorship, and administrative support of graduate students, and facilitates recent conversations on thriving versus surviving that have been promoted in recent literature. Further, we highlight that just because individuals may "get through" the PhD, a painful experience will deter these folks from considering careers in academia, which affects who (wants to) become a professor to serve as future role models or make things better for future generations of PhD students.

The longitudinal analysis of questioning students' perceptions of their advisor relationship over time are highly interesting, showing that students in later stages of their programs have a lower satisfaction with their advisors. This is potentially opposite to what other graduate theories (e.g., socialization theories) might posit, since one would expect that over time, graduate students might socialize into the expectations and norms of both their discipline and their research group environment. This is a significant value-add to the engineering literature, and shows that the superficial label of "advisor relationship" may manifest quite differently for students at different stages of their programs of study in engineering.

Together, this paper shows a more nuanced understanding of how the advisor relationship both evolves and comes to affect persistence and attrition decisions in engineering graduate programs, and from these findings, we offer implications for several stakeholder groups. First, while different departments vary in the ways that advisor matching occurs, messaging to students should center around multiple roles of advisors in engineering, and that different advisors have different mentoring philosophies. By aligning expectations early, students can select whether an advisor that is aligned well in terms of expertise area or topic would be a strong fit for what they expect a doctoral advisor to be as a mentor. These interpersonal aspects of advisor matching as a two-sided

conversation should occur early and often, potentially during graduate recruitment/visit events as well. Engineering faculty should be aware that even relationships that start positively with their students need attention to maintain a strong relationship, and that students nearing the end of their program may be experiencing additional isolation because of both the writing phases of the dissertation and because their support structure may have already graduated, leaving them lonely and unsupported. Considering how the other aspects identified in the "truth tables" affect or may be affected by/compounded by a suffering advisor relationship would be an important reflection question to pose to engineering faculty. Last, from a programmatic and structural component, we recommend leveraging required introductory graduate seminar classes to help prepare incoming graduate students for the milestones and psychosocial challenges they will encounter as part of their graduate research, including talking about managing stress, advisor issues, and mental health. Engineering faculty could also be incentivized to attend additional mentorship training; ongoing conversations around required doctoral mentorship plans evolving through funding agencies and across various institutions may be one step forward, though a "training imperative" in any context may have mixed results.

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