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RESEARCH ARTICLE

Engineering graduate students' critical events as catalysts of attrition

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Abstract

Background: While attrition from the PhD has been attributed to many high-level causal factors, such as funding, advisor relationship, and "fit" into a department, few studies have closely examined the mechanisms of attrition or why and how graduate engineering students begin to consider attrition from their doctoral programs.

Design/Method: This study analyzed interviews with current and former doctoral engineering students at research universities across the United States, collected through two closely-related studies on graduate engineering experiences and attrition consideration. We used critical event analysis as a methodological approach to understand the experiences of a subset of 13 participants, who, at some point in their graduate career, experienced a singular event that caused them to question whether to persist in their PhD program.

Purpose/Hypothesis: The purpose of the present paper is to investigate how graduate engineering students begin to question whether they should remain in their PhD programs of study.

Results: We categorized the environments in which critical events occurred into four quadrants along the lines of University and Nonuniversity Settings and Routine versus Unexpected Contexts, mapping critical events and supporting events to themes from prior literature. The findings demonstrate how seemingly mundane experiences for faculty can be cataclysmic in the eyes of the student; how critical events serve to magnify other issues that had been accumulating over time; and how students may not self-reflect on their rationale for pursuing a PhD until a critical juncture occurs.

Conclusions: Critical events are one mechanism by which students may begin considering departure from their engineering PhD programs. Some critical events masquerade within mundane contexts, like conversations or conferences (although, in retrospect, students can identify other relevant features contributing to dissatisfaction). From this work, we provide implications geared toward administrators, advisors, and graduate students on how to address and potentially mitigate critical events or their effects, including engaging in conversations about leaving.

KEYWORDS
attrition, critical event analysis, graduate education, interviews, persistence, qualitative

1 | INTRODUCTION

Graduate attrition in engineering is often overlooked, although the problem is pervasive. The Council of Graduate Schools (2008) reports that the 10-year completion rate for PhD students in engineering is only 57% for female students and only 64% for male students. These numbers are likely still inaccurate due to the ambiguity and obscurity within the process of calculating completion rates: for example, a student who leaves their doctoral program with a master's degree may be counted as a degree conferral rather than a case of attrition from the PhD program. These high attrition rates represent a substantial waste of efforts and resources for the students, as well as for faculty, departments, industry, and funding agencies. Literature indicates that approximately 80% of PhD holders seek nonacademic careers (Schillebeeckx, 2013), such that attrition from the engineering PhD yields a loss of competitiveness for industries, as well as academia. Given that attrition and Master's-level departure from the PhD disproportionately impacts women and people of color, if a diverse population of graduate students chooses to depart from the PhD, do not feel welcome in academia, or are not thriving as graduate students, there are also severe consequences for the diversity of the future engineering professoriate. Valuing diversity in engineering is an issue of justice and equity that needs to be remedied from a moral point of view (Holly, 2020) with additional ramifications for academic mentorship and role models for students (Blake-Beard et al., 2011; Buzzanell et al., 2015; Chubin et al., 2005) as we seek to make diversity in engineering the default (Pawley, 2017).

While recent literature in engineering education has turned attention toward issues facing graduate students, including competency development (particularly with writing) (Cruz et al., 2019; Hasbun et al., 2016), evolving professorial intentions (Burt, 2019, 2020), academic identity development (Kajfez & Matusovich, 2020; Miller et al., 2017; Perkins et al., 2020; Satterfield et al., 2019), and graduate attrition (Berdanier et al., 2020), there is still little known about how and why students come to question whether to stay in their programs and how they engage with the decision to leave or to stay. This conversation is critical, as the literature indicates that nearly 24% of STEM PhD students seriously consider leaving their PhD programs (Ruud et al., 2016), which is less than the 36%–43% attrition for graduate students more generally (Council of Graduate Schools, 2008), but still significant. To this end, the purpose of the present paper is to characterize how graduate students begin to consider departure from their programs.

2 | RELATED LITERATURE AND THEORETICAL FRAMING

Most graduate attrition and persistence literature resides in the Higher Education research domains (as opposed to discipline-specific domains) and has sought to categorize the factors that impact attrition, finding that a set of common external factors like academic environment, funding, and time to completion affect students' likelihood to persist (Ehrenberg et al., 2007; Lovitts, 1996; Mendoza et al., 2014; Pauley et al., 1999; Spaulding & Rockinson-Szapkiw, 2012; Xu, 2015). Golde (1998, 2005) found that socialization, departmental structures, and lack of "fit" contributed to the decision to leave. The relationship between student and advisor has also been shown to influence a student's experience in graduate school (Barnes, 2010; Hunter & Devine, 2016; Lovitts, 2001; Maher et al., 2020a ; O'Meara & Campbell, 2011). Mismatched expectations, lack of mentorship, and insufficient communication also impact a student's consideration of whether to leave their program (Barnes & Randall, 2012; Zerbe et al., 2020). To date, little attention has been turned toward the identification of specific moments or experiences that cause doctoral students to consider leaving their programs, although some work with women and racially marginalized students shows that microaggressions and hostile interactions impact belongingness (Cabay et al., 2018; Miles et al., 2020).

Attrition has been explained from psychological and sociological perspectives. Psychological elements, like self-efficacy (Bieschke et al., 1996; Braxton & Baird, 2001; Kelley & Salisbury-Glennon, 2016; Litalien et al., 2015), feelings of being "stuck" (Devos et al., 2017), work/life balance (Castelló et al., 2017), and mental health (Evans et al., 2018; Hocker et al., 2019; Hyun et al., 2006) have been documented as dominant factors in graduate student attrition. Pyhältö et al. (2012) showed that PhD students considering withdrawing from their programs have significantly higher levels of stress, exhaustion, anxiety, and lack of interest in their PhD studies than those who had not. Sociological aspects of attrition are those that attend to the structure of academia and broader disciplinary, departmental, university,

and social contexts: Research group cultures (Crede & Borrego, 2012; Walsh, 2010), formalization of mentorship or advisor matching processes (Artiles & Matusovich, 2022), and access to professional and personal resources affect student success (McAlpine et al., 2009), as do the historical traditions of engineering and academia as both gendered and raced (Pawley, 2019; Posselt, 2021).

There are some sociological contextual factors that make engineering graduate attrition interesting and different from attrition in other disciplines, especially in the social sciences and humanities, where most doctoral attrition scholarship is conducted. First, funding and time to completion are less likely to be factors of attrition for engineering graduate students when compared to other STEM or non-STEM graduate students. Indeed, studies show that approximately 80% of engineering graduate students have funding (Crede & Borrego, 2012), and engineering is considered a high and fast completing discipline, meaning that completion rates are higher and time-to-degree is shorter compared to other disciplines, especially in social sciences or humanities (Gardner, 2010; Gardner & Barnes, 2007).

Engineering as a discipline is also highly gendered racism (Pawley, 2019), as a predominantly male and White discipline. Literature shows how identities affect graduate students' experiences, as racial and ethnic minorities have higher rates of attrition due to structural racism, minoritization, and unfriendly climates (Burt et al., 2018; Sowell et al., 2015). The reports of persistent overt and covert sexism persist for women in academic engineering, and graduate students who hold multiple marginalized identities contend with a "double-bind" of sexism and racism simultaneously (Malcolm et al., 1976; Malcolm & Malcolm, 2011; Ong et al., 2011). International students, who comprise a large proportion of graduate students in the United States, must also contend with additional issues that complicate the pursuit of their degree, like culture shock, navigating academia in a language that is not their first, or lower self-efficacy in common graduate school tasks like writing (Bluestein et al., 2018; Zerbe & Berdanier, 2020).

We agree with other researchers that the decision to depart from a doctoral program is a process in which the advisor plays a key role (Artiles & Matusovich, 2022; Bahnson et al., 2019; Parker et al., 2019) and that there are often misalignments between faculty and student expectations and needs (Adrian-Taylor et al., 2007; Janssen et al., 2021). The lack of satisfaction with a supervisor can lead to overarching issues related to well-being, such as burnout and cynicism (Cornér et al., 2017; Pyhältö et al., 2017), and a lack of regulation of the issues in a suboptimal relationship can lead to negative motivational outcomes or attrition (Devos et al., 2016). The fit of a graduate student within a research group also can enhance or impede success (Maher et al., 2020b), a process also mediated by the social support that a lab group provides (Peltonen et al., 2017). Literature also demonstrates that the ability of graduate students to develop their academic identity is crucial to the formation of career trajectories and professorial intentions and is mediated by advisor relationships and modeling (Burt, 2019, 2020).

To start demystifying attrition in engineering, Berdanier et al. (2020) articulated how factors that contribute to the decision to leave may layer with each other or how students navigate the decision process itself. That work, framed through the lens of Expectancy-Value Theory, which was useful in describing how an individual's motivation toward a task (persistence in the engineering PhD) is mediated by the individual's assessment of the value or worth of that objective coupled with their expectations for a given outcome. In agreement with other studies that have proposed that themes related to graduate student experiences overlap and require disciplinary-specific lenses (e.g., Holley & Gardner, 2012), Berdanier et al. (2020) proposed the Graduate Attrition Decisions (GrAD) model, capturing factors related to attrition specific to academic engineering.

The GrAD model comprises six dominant themes: Advisor, Cost, Support Network, Goals, Perception by Others, and Quality of Life and Work, shown in Figure 1. Within these factors, there exist eight subthemes. A unique facet of this model is that the themes and their subthemes do not exist in isolation: The subthemes connect with other themes and subthemes to show an ecosystem of factors related to attrition in graduate school. This model and the supporting study highlighted that typically, no single factor unilaterally results in students choosing to leave; rather, the choice to depart a PhD program is the culmination of multiple suboptimal aspects of their experience. For the purposes of the present study, we have chosen to employ the GrAD model as a theoretical framework over more general graduate socialization frameworks (like socialization theory or communities of practice) because it was specifically created to understand the linkages between factors that lead to graduate attrition in an engineering context; is aligned with the methodological and theoretical traditions to which we commit; and influenced the framing of our interview protocol. It was also used in the coding process for our data as an a priori schema. The GrAD model was developed to understand attrition, not persistence or thriving in graduate engineering programs. While literature supports that many of the "positive" aspects of these elements (e.g., positive advisor relationship, strong support network) are important for persistence (Spaulding & Rockinson-Szapkiw, 2012), without more research, it is imprecise to assume that these attrition

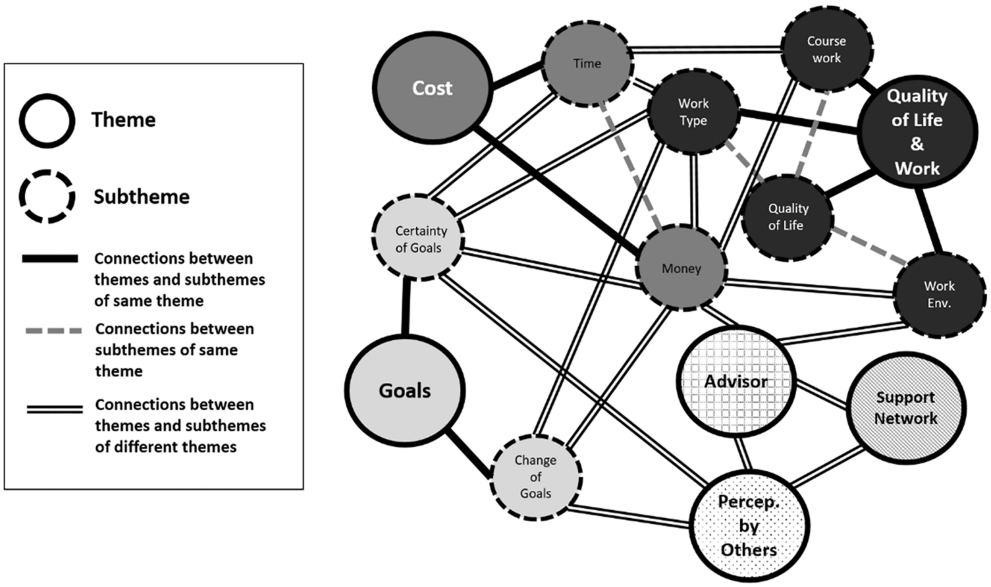

FIGURE 1 Graduate attrition decisions model from Berdanier et al. (2020). Critical events serve as a way in which students begin questioning by affecting one main node, amplifying issues, and events in connecting nodes

nodes also comprise a complete model of the mechanisms of persistence or requirements for thriving in graduate school.

It is from this point of view that we undertake the present research study. The objective of this paper is to begin to characterize how graduate students begin to consider departure, turning into what we refer to as a "questioner" (a PhD student who is strongly considering leaving their degree) to illuminate yet another piece of the graduate attrition decision-making process puzzle. For this study, we are not concerned with the outcome of the questioning process except to note that some of our participants decided to leave their programs of study (becoming "departers") while some decided to continue and had either earned their PhD or were still on track to graduate at the time of the interview. To this end, we show that not all questioners will become departers, although all departers were once questioners. Because of this fact, turning attention to investigating how engineering doctoral students come to question whether to leave their PhD programs is an important and necessary task. To our knowledge, this is the first study to investigate critical events as catalysts in the decision to depart from engineering graduate programs. To this end, this paper answers the following research questions:

1. How do engineering doctoral students begin to consider departure from their PhD programs?
2. How do adverse experiences layer to cause consideration of departure from the engineering PhD?

3 | POSITIONALITY OF THE RESEARCHERS

As researchers working with qualitative data, we understand that our positionality and personal experiences and bias have impacts on the selection of research questions, theoretical framework, and interpretation of the data and interactions with the participants (Merriam & Tisdell, 2015; Secules et al., 2021). The primary researcher on this project is a White woman, the second author identifies as a Latinx, a first-generation woman college student, the third author is a Black man. All three are graduate students who conducted the interviews independently after being educated and mentored by the last author and principal investigator, a White woman engineering faculty member with expertise in graduate-level engineering education research. The first three authors' status as engineering graduate students were valuable in the interview process with the graduate student participants because they were able to gain rapport with participants during interviews without the influence of a power dynamic.

We adhere to constructivist, participant-centered methodological traditions of interview-based research that harness participants' lived experiences (Rubin & Rubin, 1995; Wolgemuth et al., 2015) as we seek to capture nuances and

complexities in graduate student experiences and how they understand those experiences. The selection of the GrAD Model (Berdanier et al., 2020) as one of our theoretical frameworks reflects our understanding and commitment to the psychological and sociological pressures impacting a graduate student's decision-making process: We believe both the psychological elements, such as the role that changing or nascent goals, mental health, or perceptions of what others think, and sociological elements, such as normative advisor roles and quality of life and work that is influenced by the university and department culture, both affect students. Our own positionalities also influenced the research decision for this paper to explicitly focus on the experiences of participants who experienced a critical event because these stories often, as will be shown, connect to gendered and racialized experiences that resonate with elements of our own personal trajectories.

4 | METHODOLOGY AND METHODS

To capture and characterize the roles that important events may play in PhD students' decision to consider leaving their doctoral programs, we employed critical event analysis as our methodological approach that informs our methods, following the proposition by Viergever (2019) given that there is much flexibility in the precise methods proposed by which to sort and categorize data. Originally conceived in the 1950s, before the emergence of post-positivistic and constructivist paradigms, the critical incident technique (CIT) was introduced by Flanagan (1954) as an analysis tool for direct observational analysis. As well-summarized by Butterfield et al. (2005), over the past seven decades, the method now goes by many different names, such as critical incident analysis, significant event analysis, and the term we employ, Critical event analysis, which is closely linked with narrative and story-based methods for qualitative data collection and analysis (Webster & Mertova, 2007; Mertova & Webster, 2019). More modern incarnations of the technique have opened the method to retrospective and reflective interview-based accounts of events and histories (Butterfield et al., 2005); and have been employed across myriad fields like education (e.g., Weiss et al., 2020) sociology (e.g., García-Montoya & Mahoney, 2020), and nursing (e.g., Steven et al., 2020) and in engineering education (e.g., Cajander et al., 2017, Coso-Strong et al., 2018).

We align with traditions of critical event analysis as a way of interpreting constructivist narrative (story-based) data to interpret a phenomenon, and in doing so, make several theoretical assumptions. According to Webster and Mertova (2007), for an event to be able to be classified as a true critical event, it must meet a few criteria: First, a critical event must result in a turning point or change in worldview that is unanticipated, can only be identified in retrospect, and is "intensely personal with strong emotional involvement" (Webster & Mertova, 2007, p. 83). In our case, we are interested in events that caused people to consider departure from their engineering PhD program, a process that upsets ones intended career trajectory and vision of self, often stigmatized, and highly personal. To this end, aligning with our constructivist paradigms, the importance of events in recollection is in the eye of the participant, not the eye of the researcher. As such, even if an occurrence seems "small" to the researcher, we afford the participant their valuation of the event. Second, the critical event must be a "well-defined" experience: While the critical event can last for a duration of time (i.e., more than just a moment), the event itself should have a defined start and a stop (García-Montoya & Mahoney, 2020). Third, aligning with the propositions from (Webster & Mertova, 2007), not all critical events are necessarily bad or good: If an event results in an altered worldview related to the phenomenon of interest, it can be classified as a critical event. This issue has caused some researchers to begin to refer to their method as "significant event analysis," especially when using it as a tool for educational intervention (e.g., Henderson et al., 2002, 2003).

As per the methodological literature surrounding critical event analysis, critical events do not exist in isolation. Instead, like an earthquake, there are related tremors leading up to the event (although unidentified at the time) and aftershocks from the critical event that compound the effect that the critical effect has, although these can only be identified in retrospect after the critical event has occurred. Methods literature defines *like events* and *other events* as events surrounding a *critical event*. By definition, a critical event has life-changing consequences on those involved, is unplanned, is intensely personal with strong emotional involvement, and can only be identified as critical *after* the event has happened. In contrast, "like events" can only be identified after the event but are not as unique as the critical event and often repeat the experience of the critical event. "Other events" are those contextual events that may not be directly related to the critical event but are identified as potentially relevant to context after the fact and provide further background information for the critical event. As an example, if a racist interaction served as the critical event that a participant noted caused them to first consider departing from graduate school, other incidents of racism would be

categorized as "like" events, but other dissatisfactions with graduate schools, such as instances of unclear advisor expectations, would be categorized as "other" events.

Critical events analysis can only be used to capture the change in worldview resulting from a critical event: If some issues were building over time, but there was not one identifiable, well-defined, and time-bound event that resulted in a worldview change, then critical events analysis as cannot effectively capture that decision. However, it is fully possible for an individual to gradually be unhappy or dissatisfied with any number of different issues but then experience a critical event where they begin questioning whether to depart and then, in retrospect, can understand how "like" and "other" events contributed and are contributing to their changed worldview.

4.1 | Participants, recruitment, and data collection methods

The participant sample was created from two related NSF-funded studies with related aims of capturing engineering graduate student trajectories and experiences in considering attrition from likely "completers," "questioners" (those questioning whether to stay or depart from the engineering PhD), and "departers" (those who left their PhD program without a PhD). In our sample, all the departers took a Master's degree rather than leaving with no degree. Because it is demonstrated in literature that international students have much different attrition rates in engineering (Council of Graduate Schools, 2008) and experiences in graduate school than domestic students (Adrian-Taylor et al., 2007; Click, 2018), our studies focused on domestic US engineering graduate students. The specific details of both studies can be found in previous literature (Sallai et al., 2022; Zerbe et al., 2020), but for the purposes of this paper, the two data sets can be considered together for several reasons. First, both studies were designed as qualitative interview studies seeking to investigate graduate experiences and trajectories into and out of engineering graduate programs for engineering graduate students at research-intensive universities in the United States. Second, the methods for recruitment of participants and sampling of participants were equivalent. Third, a substantial portion of the interview protocol was the same: asking questions about pathways and trajectory to and through engineering, thoughts of leaving their graduate programs, including when they first considered leaving, factors contributing to their consideration, and frequency of consideration of departure. The interview questions focused on the psychological and sociological aspects of graduate school, and prompts were included to probe the dimensions of the GrAD model (Figure 1).

In both studies, engineering PhD-student participants were recruited from high-ranking PhD degree-conferring universities in the United States, as identified by the American Society for Engineering Education (Roy, 2019) (the top 25 universities for one study, and the top 50 universities for the other study) via email to administrative assistants, requesting them to forward the email to engineering graduate students. The recruitment emails requested students to complete a short screening survey that collected demographic and educational information, attitudes toward various facets of graduate school and attrition, and interest in participating in an interview. We applied purposive, stratified, and maximum variation sampling methods (Creswell & Poth, 2016) to select participants to invite for an interview. Criteria for selected participants included academic level, demographic diversity, indications of a high likelihood to leave their graduate program, and interesting cases based on an open-ended question to potential participants requesting "anything you think we should know about [their] experience in graduate school" in the screening survey.

The subsequent interviews sought to understand participants' experiences in graduate school, as well as any contributing factors in their considerations of departing from their PhD. Interviews were conducted and recorded via Zoom and lasted approximately an hour. Participants were compensated for their time with Amazon e-gift cards. All audio files were transcribed by a professional transcription service and checked for accuracy. Every participant was assigned a pseudonym, and any identifiable information was redacted in excerpts selected for publication, especially in contexts that are highly unique or concerning individuals who may be able to be identified based on their demographic data.

Considering the participants from both studies now as a single data set, we had, in total, 52 accounts of graduate experiences from participants who were current questioners or departers that met the screening criteria. In the initial readings of the interviews, it became evident that some of these participants experienced triggering events that served as abrupt turning points in their degree intention, motivating the research team to pursue critical event analysis as a dominant analysis tool for this study. Using the definitions of Webster and Mertova (2007) to define a critical event, as well-defined in time; resulted in attrition consideration (i.e., changed worldview); unanticipated; and only identifiable as a critical event in retrospect, we identified that 13 participants' decisions to consider departure were linked back to a singular event. For transparency, we note that six participants came from one of the original studies and seven participants from the other. Since engineering attrition is just beginning to be investigated in-depth, examining these critical

events separately from the other narratives will elicit a deep understanding of this specific mechanism before investigating attrition mechanisms for those who have a more gradual path to questioning departure. The interviews for the 13 participants then were deeply investigated using critical event analysis described further below.

Table 1 introduces our participants by their pseudonyms, their engineering discipline, the demographic characteristics of our participants, and the stage in their program at the time of the interview. Of note, nine of our 13 selected participants were women, three identified as Hispanic, one identified as Black/African American, and one participant identified as being from another racial/ethnic demographic group without identifying. The participants in this sample overrepresent women and students from minoritized racial/ethnic groups in engineering. In comparison, in 2019, only 24.1% of doctoral engineering degrees across disciplines were awarded to women, and only 3.9% and 6.1% of doctoral degrees were awarded to Black/African American and Hispanic students, respectively (Roy, 2019). This overrepresentation is an important attribute to highlight as recent literature (e.g., McGee, 2020; McGee et al., 2019, 2022) notes that the pressures on graduate students are different for students marginalized in engineering as a racialized and gendered field of study.

Four participants identified as "early-career" (in the first 2 years of their PhD, before qualifying exams), six were mid-career (in years 3 or 4 of their PhD, before the dissertation proposal), and three were late-career (in or beyond year 5 of their PhD program.) This distribution of participants is interesting, given that other reports note that most attrition occurs in the first 2 years of a PhD program (Sowell et al., 2015). The participants came from the disciplines of biomedical engineering ($n = 1$), civil engineering ($n = 2$), chemical engineering ($n = 2$), engineering education ($n = 1$), environmental engineering ($n = 3$), and mechanical engineering ($n = 1$). We chose not to report the disciplines in the table to avoid potentially identifying participants.

4.2 | Data analysis and interpretation methods

We employed the methodological approach of critical event analysis as a way to identify and characterize engineering PhD students' change in worldviews (Mertova & Webster, 2019) as they began to consider departure from their graduate programs. The data were analyzed and characterized in three phases. In the first phase, the researchers identified all participants whose questioning processes were triggered by a critical event: an event that, in retrospect, was the beginning of the participants' questioning. For the 13 participants that did experience a critical event, the researchers employed a coding worksheet that facilitated the researchers' articulation of the critical event and all *like* and *other* events. For clarity, in this paper, we use the term "supporting event" to include both *like* and *other* events. Each transcript was initially analyzed by one member of the team and then finalized by consensus with the rest of the team.

TABLE 1 Participant pseudonyms, demographic information, and stage in graduate school at the time of questioning

Pseudonym	Gender	Racial/ethnic identity	Stage in graduate school
Amelia	Woman	White	Early-career
Angie	Woman	White/Hispanic	Early-career
Carla	Woman	Hispanic	Early-career
Darryl	Man	Asian	Mid-career
Diana	Woman	Black/African American	Late-career
Heidi	Woman	White	Mid-career
Kendall	Man	White	Mid-career
Melissa	Woman	White	Late-career
Morgan	Woman	White	Mid-career
Sharon	Woman	White	Mid-career
Spike	Man	Hispanic	Early-career
Tony	Man	Another race	Late-career
Willow	Woman	White	Mid-career

During the coding process, the transcript excerpts related to critical and supporting events were denoted for further thematic analysis.

In the second phase of analysis, the interview excerpts related to the critical and supporting events were analyzed using thematic analysis, employing the GrAD model as an a priori framework for the main themes, given that it was created to understand graduate engineering student attrition decisions. In this stage, we made the research decision to allow for emergent coding to help us develop new understandings through an abductive approach (Timmermans & Tavory, 2012) using a constructivist paradigm (Charmaz & Belgrave, 2012). All themes and subthemes of the existing GrAD model were employed, with a few emergent additions. As one example, we added a psychological code to the "cost" theme when participants discussed the loss of well-being or mental health. As another example, we specifically noted when a former or current advisor was the cause of a critical event if a participant had switched advisors, adding nuance to the "advisor" theme. After conducting this analysis, each of the critical events were identified and summarized with a brief descriptor of the critical event and mapped to the respective GrAD nodes; all supporting events were similarly mapped to GrAD nodes based on the rich contextual data surrounding the event, as captured through the interview.

To make sense of how critical events occur, we sorted the critical events fell into four quadrants describing the settings and contexts of the situation. We define setting as the realm within which the critical event occurred, with *University Settings* being those within the local campus context of graduate school (e.g., research, meetings), and *Nonuniversity Settings* being outside of the local university setting (e.g., conferences, family circumstances). While, by definition, critical events are unpredicted and only recognized as critical events after reflection, we promote that the contexts in which these critical events occurred were either *Routine Contexts* from the point of view of the student participants (e.g., communication with an advisor, attending a conference), or *Unexpected Contexts* from the point of view of the students (e.g., an altercation with an advisor, an advisor switching universities, a job offer).

Of note, we adhered to our constructivist, participant-centric epistemology when framing these categories and definitions, proposing that something that is routine to a faculty member may be unexpected by a student. One example might be taking a leave of absence: A faculty member, over the course of years of experience, may often notice students navigating difficult situations or taking leaves of absence periodically to deal with family or health issues (as examples), but these may not be publicized to other students, such that having to take leave would be unexpected from the point of view of a student. We also posit most graduate students likely do not plan to have a life-threatening illness that forces them to take a leave of absence. Similarly, things that faculty may feel are routine, such as meeting with a department head, may not be expected from a student's point of view, especially if it is outside of the norm for that department. To this end, we worked from the rhetorical cues of our graduate student participants as they identified whether the critical event happened in a context that was routine for them or a context that was unexpected for them. Most of the participants in "unexpected" contexts explicitly noted the unusual circumstances, if something was out of the ordinary, not part of their expectations, or atypical for their advisor or department. The "expected" context participants tended to rhetorically show a juxtaposition with the routine contexts in which their life-changing critical events happened. If the participants did not clearly note the expectedness, we interpreted other cues from the full hour-long interviews. For example, in other parts of the interview, we asked questions about advisors, how frequently participants meet with advisors, and the evolution of the advisor relationship, helping us to interpret when an interaction was out of the ordinary. Two researchers characterized each critical event into these dimensions by consensus, informed by the interviews, resulting in the final characterization of the data, as shown in the findings section.

We carefully heeded standards of care and quality throughout the qualitative planning, recruitment, data collection, and data analysis and interpretation processes, following recommendations from Walther et al. (2013) to consider aspects of quality in both the "data making" and "data handling" stages of research. Our methodological recruitment decisions and semi-structured interview methods, grounded in the most recent theory in engineering and attrition literature, demonstrated our commitment to theoretical and pragmatic validation (i.e., how well our study fits within both theory and empirical domains). In the application of procedural validation, we carefully adhered to the methodological considerations of critical event analysis, as the data were analyzed, interpreted, and presented in this paper. Through the analysis process, the team of researchers regularly met to discuss the identification of critical and supporting events and the relationship of those events to aspects of the GrAD model, working to accurately interpret the participants' understandings of their own critical events. This iterative and collaborative process continued through the analysis, interpretation, and writing stages of this paper to ensure that we accurately represented the lived realities of our participants as individuals and as a group, attending to issues of ethical validation. We also carefully contended with which aspects of our participants' experiences were most salient in the construction of this paper, which participants we chose

to highlight in this publication, and which findings contributed most to theory and practice, in conscious regard for communicative validity for the disciplines of engineering education, traditional engineering, and higher education.

5 | LIMITATIONS

As with any study, there are limitations to this work. First, because not all graduate students that may be considering departure have a singular or critical event that is an identifiable *start* to their questioning processes, our findings illuminate the existence of a critical event as only one type of mechanism by which the attrition process may begin. Second, although the demographic composition of the participants highlights the experiences of women and racially marginalized engineering doctoral students, we are likely missing experiences that uniquely affect participants from other groups than those represented in our sample, including those with multiple intersecting identities or different gender identities. Therefore, the specific examples of critical events in this study are nonexhaustive, although we do posit that the contexts of any critical events could be categorized using our analysis framework. We also acknowledge that our data do not include international engineering doctoral students, who experience additional pressures with respect to cultural expectations, language barriers, political and visa issues, isolation, and discrimination. Further, it is plausible that those graduate students who had adverse experiences or experiences they wished to share were more likely to complete the initial screening survey, such that the qualitative data we present cannot be generalizable to all graduate students. Despite these limitations, this work is a valuable addition to investigate the moments that engineering doctoral students started to consider leaving their PhD programs, a topic not previously investigated in graduate engineering education.

6 | FINDINGS

The critical events can be visualized as quadrants related to the contexts in which the critical events occurred. We sorted the critical events into whether they occurred in a university setting or a nonuniversity setting and whether the contexts in which the critical events were situated were routine or unexpected. While, by definition, all critical events are unpredicted from the point of view of the participants, the contexts in which the critical events occurred may not be surprising (e.g., a conference or a meeting with an advisor if meetings happen regularly). Figure 2 conveys several layers of information about our participants, including the students' outcomes regarding persistence at the time of the interview, the nature of the critical event that served as a catalyst for each participant to begin to consider departure, the GrAD nodes affected by the critical and supporting events, and the stage of the graduate school of each participant when the critical event occurred. Shading indicates the participant's decision to depart at the time of the interview. We did not seek to have an even distribution of participants falling into all four categories; however, the fact that participants and those who chose to ultimately depart fell into all four quadrants is an interesting summative finding.

Before examining attrition decisions through critical events analysis, we want to highlight the identities of the participants. Of the 13 participants in this study, all but one had at least one non-normative identity for engineering, either by gender, race, or both. While the purpose of this study was not intended to investigate departure decisions only for students with marginalized identities, it is noteworthy as a contextual feature to understand that some events may be more "critical" for some populations or individuals than for others.

In the following sections, we present the stories of one participant from each quadrant through a critical events perspective. Although each participant's story is unique and rich, the selected participants are highlighted because they show attrition decisions occurring in a variety of contexts, impacted by nearly all the nodes in the GrAD model. As we present the analysis of each of the critical events, we explicitly note how both the critical event and supporting events—identified by our participants in retrospect— affected their graduate school experiences. As shown in Figure 2, the critical event and supporting events together represent several parts of the GrAD model, showing the interconnectedness of the nodes. We start by presenting the Routine Context|University Setting quadrant, which is represented by only one participant, Willow, which shows how even very predictable contexts can host critical events. Then we move to discuss participants whose critical events occurred in the quadrants of Routine Context|Nonuniversity Settings, then Unexpected Context|Nonuniversity Setting, and then Unexpected Context|University Setting.

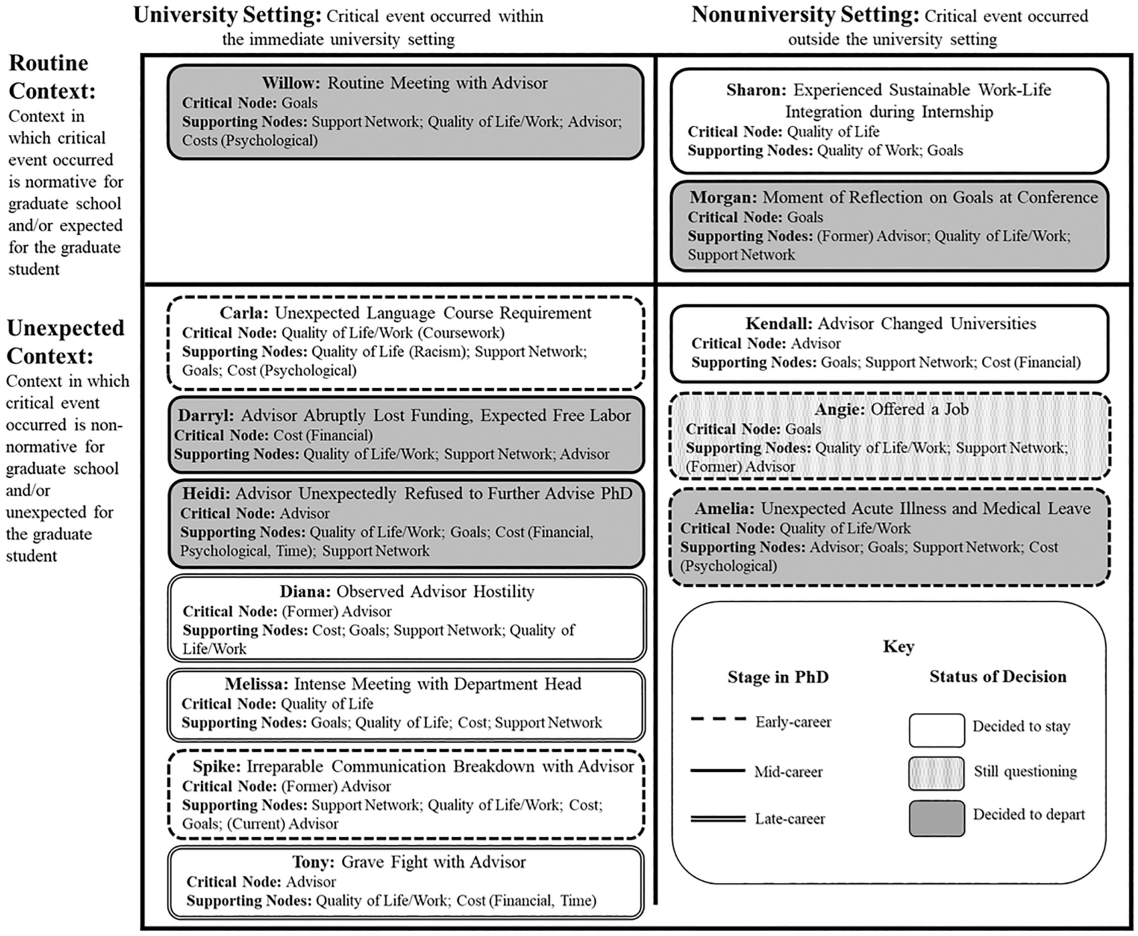

FIGURE 2 Characterization of the critical events that caused students to consider departure from the engineering PhD

6.1 | Routine context|university setting for critical events: Willow

Willow's critical event occurred during a routine meeting with one of her research advisors when he asked her why she wanted a PhD. In her words, "And it kind of hit me, I was like, 'I don't know, actually. Why do I want a PhD?'" While the context of the actual critical event—an advisor meeting—was academic in nature and is a routine part of graduate school, in hindsight, Willow had several supporting events that allowed this meeting to become a critical event. She entered graduate school not because of a passion or a specific career goal (*Goals*), but because she had lukewarm experiences in previous coops and relatively positive experiences with research. Willow's experiences in graduate school started suboptimally. She had been recruited to work for a professor that was subsequently placed on leave (*Advisor*). As a result, she was assigned to be coadvised on a project on which she had not been hired to work (*Quality of Life/Work*), advised by relatively absent professors (one advisor's wife was quite ill, and the other was a professor emeritus) who were hostile with each other (*Advisor*). The project itself seemed to be nebulous, not impactful (*Quality of Life/Work*), and unrelated to the research of anyone else in her group (*Support Network*). She also had trouble connecting with other peers in graduate school, discussing how more senior graduate students seemed too busy and the rest of her cohort were already good friends with each other (*Support Network*).

To pursue graduate school, Willow and her partner had moved to a new city, were relatively isolated, and both realized they struggled with mental health issues (*Costs—Psychological*). The lack of structure in Willow's lab amplified her anxiety and depression:

> I came into a really well-respected lab, and I was afraid to show or say what I didn't know. I was really afraid to ask questions, and I just kept getting it in my head, like, my advisor wrote a book on this topic, I should just go read the book and I'll understand it. And I had to sit down and try to read the book and I

> just ... I wasn't getting anywhere. [...] And that just kind of spiraled into me guilting myself that I wasn't understanding it, but I wasn't really doing well. And so, I did okay in classes and everything, but research progress without structure was really hard.

Despite these hardships chipping away at the dominant tenets of the GrAD model (*Support Network, Quality of Life/Work, Advisor*), Willow had not considered departing from her PhD until that fateful meeting with one of her research advisors, who asked her the critical question about why she wanted a PhD. In Willow's words, she did not have a goal that outweighed her perceived costs:

> And so, I was like, "Well, what's the point in getting a PhD?" If I wanted to teach but maybe in a different topic, okay, then a PhD, you know, finishing my PhD and then maybe trying transition topics would be worth it. But I don't really know what I wanted to do. And I started kind of looking at like, "Well, what options are out there?"

Willow's experiences show how previous events, although perhaps more disruptive than the critical event (e.g., getting placed on a different project with different advisors than intended or handling mental health issues), were not identified as *the* critical event causing departure. These events, told as supporting details in retrospect, show that the entry point to questioning came by way of a conversation with an advisor, and that conversation was the catalyst that finally disturbed the system. As Willow reflected on her experiences and her changing goals, she arrived at her decision to depart with a Master's, aiming instead for a research support position that combines the things she since reflected on enjoying. Since her subsequent reflections on her trajectory assured her that she did not "need a PhD," Willow's critical event served as the catalyst for her to depart with a Master's degree.

6.2 | Routine context|nonuniversity setting for critical events: Morgan

The next quadrant into which critical events occurred is that external to a graduate school context but plausible part of a graduate student's career. Two participants fell into this category: Sharon's critical event was an internship, which provided a time to reflect on goals, and similarly, Morgan's experience highlights how a research conference provided the opportunity to step outside of the day-to-day environment provided an impetus for reflection on goals for a PhD.

> So, the moment when I decided that I really wanted to leave was actually when I was in Switzerland at [a] conference, that was now three years ago in May. And I was looking around at all of the people there, and I found it interesting, but [...] my advisor was with me and he kept being like, "Oh, well, you could postdoc with this person, or this person, or this ..." And it was like, "Oh." I started to realize that I didn't know if that was for me. And I was looking at all these people who were super excited about the research they were doing. And I found mine interesting, but I don't think I would consider it, like, consider myself excited about it. So I started to really feel like my goals had shifted and I didn't necessarily know what my goals were, but I knew they weren't to get a PhD.

Morgan initially decided to stay for a PhD after her master's because she won a NSF Graduate Research Fellowship, which allowed her to start in a new, more collaborative laboratory, with a supportive advisor (*Quality of Life/Work, Advisor*), having had adverse advisor relationship issues with her former master's advisor (*Former Advisor*). After Morgan's critical event at the conference where she reflected on whether she wanted a PhD (*Goals*), she was able to articulate what parts of her job she really enjoyed doing, especially outreach, data collection, and lab management (*Quality of Life/Work*). While she did not discuss her questioning thoughts with her advisor, Morgan relied most heavily on the support of her husband (*Support Network*), who was also questioning whether he wanted to continue his PhD (in a different discipline). She ultimately decided to leave:

> And so, we were kind of like, "Well, we could wait on this decision," but with the NSF, our funding started August 1st, and I just decided that I didn't want to have to deal with giving any of the funding back or something if I started the year and decided to leave. And so, that also led to the speed of the decision. So, May was when I started to think of, like really seriously thinking about leaving and by July, I had told my [PhD] advisor I was leaving.

Morgan's critical event allowed her the perspective to reflect on other nodes of her experiences that impacted her decision: Her past and current advisor relationships (*Advisor*), her main support structure (her husband, also questioning) (*Support Network*), and her changing goals for a PhD (*Goals*) and the parts of her education and research she really did and did not like (*Quality of Life/Work*). Morgan departed, earned her teaching license, and now teaches high school science.

Morgan's experience shows another example of how even seemingly benign and routine academic experiences, such as a conference, can allow students to step back from normal life and consider other options and to induce reflection on other elements of graduate school that are or are not progressing as they would have hoped, serving as an impetus for attrition decisions.

6.3 | Unexpected context|nonuniversity setting for critical events: Amelia

We characterized the critical events of three participants, Kendall, Angie, and Amelia existing in contexts that were external to graduate school and completely unexpected. As an example of perhaps a most unexpected event, we present Amelia's experience with health issues that threatened both her physical and mental well-being (*Costs, Quality of Life/Work*) that required a leave of absence. While taking the time for treatment and recovery, she realized that she "wasn't happy in the Ph.D. program" and that she was "just done with graduate school at that point." Amelia had not had an easy transition to graduate school, despite having extensive undergraduate research experiences and being successful in coursework. She tried multiple labs across a couple of departments to do her best to find a good advisor fit (*Advisor*), but both of Amelia's graduate lab experiences deteriorated quickly:

> The first one, it was more of just an entire lack of communication, once the other graduate student left. So I didn't know what the expectations were and I also didn't ask them. [My advisor] wasn't happy with how often I was in the lab. But I didn't know that, "cause he had told me to focus on classes that semester, "cause I was taking a larger course load. And so I wasn't really coming in that much. And then it turned out he thought ... He was expecting more, and never communicated that up until the point that he asked for my key back [...] And so the second one, [...] I would get in at like 8:00 AM, other grad students were getting in closer to 11:00 AM. But he would just stop by at 6:00 PM to make sure everyone was still in the lab. Before he left for the day, he wanted to make sure everyone was still there, working. And one of our last meetings, he's like, "If you're not in the lab for 12 hours a day, you're not going to get a Ph.D.," From me, I was like, "That's not going to work for me."

While navigating these issues related to the quality of life and work, changing goals, and advisor relationships, Amelia also described battling anxiety, depression, and an eating disorder that resulted in severe illness (*Psychological Cost, Quality of Life/Work*) and required her to take medical leave. During the leave of absence, Amelia spent time considering her experiences and whether she wanted to continue (*Goals*). After some time, she returned to school but to finish a coursework-based master's degree rather than a PhD.

6.4 | Unexpected context|university setting for critical events: Carla

Finally, seven participants experienced critical events that happened within the context of graduate school but were unanticipated. Many of these involve altercations with or seemingly abrupt decisions by advisors. From the point of view of faculty, these events may not seem important enough to be critical events. However, due to the definition of the critical event—being identified *by the participant* in retrospect as the moment they began questioning—these issues, in fact, "count" as critical events. However, recalling Figure 2, only two of these participants ultimately decided to leave their programs, indicating that these difficulties are not insurmountable and that not all students who question end up departing their programs. However, for the purposes of this paper, we would like to turn this conversation to the experience of Carla, whose critical event illuminates a potentially racist ramification of graduate policy.

Carla, a native of Puerto Rico, had plans to be a professor but experienced several layers of difficulty in graduate school at a predominantly White institution (university) (PWI) in the mainland United States. Her institution required her to take an English test, although she is a United States citizen and fully fluent in English. The university then

required her to take an extra remedial English course. The extra required course was a fourth course on top of three graduate-level engineering courses she had to take in a single semester and served as the critical event that caused her to consider departure. In that semester, she was overwhelmed with coursework that she felt was unjust and racist (*Quality of Life/Work*). The additional course exacerbated other issues. The extra intensive English course took effort away from her time to spend in the laboratory, such that she had made less research progress than intended (*Quality of Life/Work*). It also limited the time she could devote to her technical coursework, and she perceived that she struggled more than her peers (*Quality of Life/Work*). Further, all these additional pressures detracted from the ability to maintain her personal network (*Support Network, Costs*):

> This semester, I think I should just finish with the master's and leave and do something else, "cause like, especially because of my family [...] Sometimes if my parents or my grandma are calling. I'll just look at the phone and I'll feel bad to answer because I know I'm just gonna lose time from studying or something like that [...] I'm a person that puts family first, so if they're calling, I'll always answer, and I'll just leave school aside. So that's kind of the worst part yet. And also having to take that English class, that's pissing me off every time I went to that classroom, it was just like, why am I here?

The marginalization and otherness that Carla felt in the remedial English class were compounded through events of blatant racial harassment on and near campus (*Quality of Life/Work*). These caused her to further evaluate whether she should stay at that university, feeling marginalized by the institution (per the required English course), by the racial incidents, and by her White friends not conceptualizing the severity of the racial incidents (*Support Network*). Carla attributed her persistence to diversity-focused affinity groups on campus (*Support Network*), noting that even in these groups talking about leaving and changing her goals (*Goals*) is stigmatized:

> I only mentioned it once to one of my friends and he was like, "What are you talking about? You are not gonna ... Are you ...?" He was just joking, he thought I was joking. I was like, "But I actually think about it a lot." But, yeah. So I think it's not that common. I don't know, after that day I haven't told that to anybody.

Carla's experience demonstrates that policy aimed to boost language skills catalyzed a cascade of unanticipated consequences that had direct impacts on her research work, coursework, feelings of belongingness, and cultural identity. In this way, we note the node of quality of life and work (of which coursework is an element) linked with other aspects of quality of life/work, social support networks, and goals in ways that may not be immediately apparent.

7 | DISCUSSION AND OPPORTUNITIES FOR FUTURE WORK

This study is the first to illuminate how the influence of a single critical event can be one mechanism by which graduate engineering students begin considering departure. Consequentially, there are two main contributions to the literature that this study offers that are also avenues for future work: The perception of what makes a critical event "critical" from the point of view of various stakeholders and the role of reflection in addressing changing goals with respect to the PhD.

(1) Critical events may seem small and/or expected to faculty but may be big and/or unexpected to graduate students because they catalyze the impact of other issues.

One of the biggest contributions of this study lies in just how impacted graduate students are by seemingly mundane circumstances about which most faculty may not think twice. In some cases, like Willow's, the critical event with the advisor was just a routine meeting. It is likely many advisors would not consider asking about a student's goals to be a sensitive question that would have worldview-altering effects. Similarly, seasoned advisors may expect some conflict to arise over the course of a PhD (Adrian-Taylor et al., 2007), but graduate students likely are not expecting conflict, nor are trained to deal with in-the-moment conflict (and are potentially affected more in conflicts than the advisor). Indeed, Pyhältö, Vekkaila & Keskinen (2012) showed that supervisors' perceptions of challenges and resources are not in alignment with those of their doctoral students.

We also note here that the myriad university and departmental disciplinary norms may impact how graduate students perceive critical events. As a few examples, in very large departments, it may be very rare for graduate students to

speak with department heads, whereas in smaller departments, it may be common. Some engineering departments may only admit as many students as they have guaranteed funding for, whereas other departments make offers to graduate students with the promise of fewer years of funding or even without guarantees of funding, with the expectation that graduate students will find an advisor with funding. We argue that most engineering graduate students are typically blissfully unaware of the mercurial ways in which funding is sometimes pieced together, meaning that few graduate students expect their advisors to suddenly run out of funding. These issues of "knowing the game" may be exacerbated for first-generation doctoral students, who often are more impacted by financial issues (Holley & Gardner, 2012; Gardner, 2013) or who may not have the academic or social capital to help them navigate the hidden norms of graduate school (Gardner & Holley, 2011).

It is not our goal in this research to arbitrate, figure out the "truth," or determine "fault" in these critical events: Instead, we take the whole of the study to illuminate a tenuous imbalance in the student-advisor relationship that can prompt large reactions (a student considering departure from the PhD) from interactions that are small from the advisor's point of view (e.g., asking about why a student wants a PhD). To this end, our study also opens the potential for future research exploring whether certain events are more critical to certain populations, considering that of the 13 participants, only one identified as a White man—the "default" identity in engineering (Pawley, 2017). To that end, while some of the events may seem inconsequential from an outsider's perspective, we must take care not to label these students as "too sensitive." Rather, given their identities, it is plausible that they carry with them extra psychological burdens from systemic discrimination (e.g., Posselt, 2021) that are part of the background of their life.

The present analysis of critical events shows how students begin the questioning process depicted by the model. The specific critical events for our participants can be attributed to a single node of the GrAD model, which serves as a catalyst to accelerate the effects of other nodes. For example, Willow's critical event was explicitly related to her realization that she had no real reason for a PhD, but illuminated issues related to advisor issues (being passed around on projects she was not hired to do), mental health, and (lack of) support network. Although there had been issues related to those other nodes prior to the critical event, only with a critical event did she consciously begin to consider attrition.

Out of this research, we call attention to how seemingly unlinked facets suddenly become salient to each other from a graduate student's point of view, as noted by the fact that the critical and supporting events in our participants' experiences represented more than a single node of the GrAD model. For example, Carla's extra class—which from the outside seems to be a standard, relatively minor curricular requirement—disrupted links with her support network and quality of life and work, cultural identity and values (time communicating with her family), and her academic performance. We as authors worry that, for students in similar situations from already marginalized or disenfranchised groups, seemingly benign additional requirements might serve to further inhibit success and belongingness in a department if the extra coursework comes at the expense of technical work or connections with family and building a support network in graduate school. It is regrettably plausible that underperformance—even if it can be explained by having to devote extra time to additional coursework above and beyond the requirements for other students—might be interpreted by faculty as a lack of commitment to research, with negative consequences for marginalized students, or worse, might seemingly confirm dangerous, inaccurate, and discriminatory racial stereotypes. The coupled effects from seemingly unrelated factors in determining attrition pathways is an interesting area ripe for future research that could be especially useful for understanding mechanisms of attrition for students from already marginalized backgrounds.

(2) Graduate students have not been guided in reflective practice and may not address or re-address goals until a critical event.

The critical events revealed in the findings and the backgrounds against which they were set the importance of dedicated time to reflect on well-being. We noticed this absence of reflection clearly in our data: Until the critical event occurred, the participants did not discuss spending time considering how their goals may be changing or how issues were affecting them. Indeed, several described how time away from their formal program and work environment, for example, even a conference or an internship, gave them the time, space, and perspective to re-evaluate their graduate school experiences. The most poignant example of this is perhaps Amelia's, whose leave of absence for health issues gave her space to realize she did not need or want to continue with the PhD. Further, the stigmatization of attrition may prevent students from engaging with these feelings with peers: When Carla started to talk about departure in her social network, she was deterred from engaging in deep reflection and in meaningful, supportive peer networking because of flippant reactions from her friend.

Reflective practice (Schon, 1991) has been applied to a variety of fields, from engineering design (e.g., Adams et al., 2003) to mentorship (e.g., Luft & Roughly, 2016; Prudhomme et al., 2003). While often employed in the engineering context as a toolset for improving design thinking, there is no significant research on the role of reflection in

the engineering graduate student socialization process, although there are other works that point to the importance. For example, Burt's (2020) study showed how one graduate student developed professorial intentions over time after observing his advisor as a faculty model and learning to identify as a faculty member. Undoubtedly there was a great deal of reflective practice that accompanied this transition. Similarly, Kirn's work often employs Future Time Perspective as a guiding theory (Godwin & Kirn, 2020; Kirn & Benson, 2018; Tsugawa-Nieves et al., 2018), capturing how students view themselves in their futures, an element that also requires reflection. While not framed through theories of reflective practice, the ability to plan a degree program with the end in mind is undoubtedly a valuable skill. There is substantial future research that could be accomplished in considering how reflective practice can guide students' formulation of career trajectories, and we posit that reflection can be scaffolded through other professional development platforms, such as the use of individual development plans (IDPs).

To this end, it is important to note that not all questioning leads to departure. Of the 13 participants in this study, for example, at the time of the interviews, eight students decided to persist, and one participant was still deciding. This distribution shows that the process of questioning is not irreversible, especially for the critical events that focus on relationships (such as the advisor relationship). However, it is unclear whether the re-forged links and nodes (e.g., advisor relationship, goals) are stable and healthy after resolving a critical event or whether—even if the nodes are mended—the linkages and nodes may be more sensitive to future "like" events or different critical events. In related work, Devos et al. (2016) showed that students in "misfit" advisor relationships who address and regulate the problem over time have positive motivational outcomes toward their PhD, whereas students who fail to address issues or reach only a temporary resolution yield negative motivational outcomes. Accordingly, investigating the longitudinal erosion of nodes and capturing longer-term impacts of critical events on professional trajectories (e.g., how adverse prior advisor relationships affect students after switching research groups) is an opportunity for future research.

8 | IMPLICATIONS FOR FACULTY, ADMINISTRATORS, AND GRADUATE STUDENTS

From this study, we put forth three main implications for stakeholders in graduate education, useful for faculty mentors and graduate students themselves. Although this study only peripherally addressed policy pertaining to Carla's experiences, there are likely aspects of these implications that can be extended into policy or onboarding materials for incoming graduate students and faculty.

8.1 | Plan for the imbalanced nature of the advisor-graduate student relationship

Each advisor may oversee multiple graduate students, undergraduates, and postdocs, all of whom require varying amounts of support. Each graduate student, however, usually has just one advisor, and that social imbalance can result in communication issues. While there is no solution to the imbalance problem, we suggest acknowledging this imbalance with incoming graduate students in an open conversation. Recognizing the significance and centrality of the role in a graduate student's academic development could allow faculty to identify interactions that will have a greater impact on a student than what faculty might expect. For example, a terse conversation with a student may be just one of the dozens of tense conversations a faculty member may have over the course of the day, but for that one student, that may be the only interaction with that professor all week.

In planning for the power imbalance, graduate students should be encouraged and empowered to pursue social and professional support relationships from study groups, affinity groups, and student organizations. Engaging in deliberative conversations about developing networks of multiple mentors and various resources around a university follows best practices from this research and from mentoring literature in general (e.g., de Janasz & Sullivan, 2004; Wallace & Haines, 2004), understanding that one single mentor cannot provide support in all areas of life to another person. Administrators responsible for graduate students at the college or department level could support orientations and workshops designed to teach students how to develop a mentoring network and how to be an effective mentee in these different relationships, understanding that having a less-centralized support network can help graduate students weather the inevitable challenges of graduate school with fewer traumatic instances.

8.2 | Reflect on goals early and often

Other literature in graduate and postdoctoral engineering education encourages the use of documents like Individual Development Plans (IDPs) as a way for scholars to communicate about future goals and plan experiences to help meet their own goals (e.g., Chakraverty, 2020; Vanderford et al., 2018). We understand some faculty may resist formal required administrative duties, but we propose that at least engaging in regular reflection on goals and changing goals (and modeling those activities with respect to an advisor's own goals) could be very useful, helping students be comfortable with asking and answering sometimes difficult questions about goals. Many new graduate students may hold incomplete or inaccurate conceptions of expectations and norms (Zerbe et al., 2020) or even superficial or misconceived reasons for pursuing graduate study (Borrego et al., 2018). Ideally, faculty themselves would engage in self-reflection to model or demonstrate resilience in the face of failure or changing goals to their students as a form of disciplinary cognitive apprenticeship applied to graduate school (Austin, 2009).

One opportunity to begin to instill goal setting and reflective practice is in orientation courses or colloquium series, where graduate students often begin to learn about the breadth of research and resources available to them. Regardless of whether individual advisors are required to help students develop official IDPs, students could be introduced to effective goal setting to encourage reflective practice. Graduate students can be empowered to take agentic control of their futures and goals, articulating original conceptions or goals for graduate school so that if things change, they can reflect on those changes. Faculty and graduate students alike should be prepared to answer challenging, reflective questions, with the understanding that this reflection is an important part of professional development. With these steps taken, we propose that the question "Why do you want a PhD?" would not provoke a crisis.

8.3 | Be prepared for hard conversations about leaving

Talking about questioning and leaving graduate school is an uncomfortable topic for many advisors, particularly because the ability to graduate PhD students is closely aligned with requirements for promotion and tenure at research-focused institutions. Some advisors may worry that by talking about leaving, students will suddenly consider leaving: However, this research qualitatively shows that even students who seriously consider leaving their PhDs sometimes decide to stay, especially if critical elements and relationships can be repaired. If faculty encounter students oscillating in their decision-making processes, they should be conscious that after a "critical event," the surrounding events and experiences become more salient to the question of leaving, even seemingly minor events and experiences. Care must be taken to re-establish trust or security in as many of the nodes of the GrAD model as possible.

Faculty who serve in administration as supervisors or advisors, graduate chairs, program coordinators, ombudspersons, or deans of graduate education might consider that there may be multiple related issues in the background that are factoring into a student's decision, whether or not they are easily articulated. In advising students in courses of action, especially in circumstances that require mediation, those in power should be aware that students may not feel comfortable raising all their concerns, lest they be labeled dramatic or emotional. Further, to avoid or prohibit talking about leaving with graduate students who are questioning is an educational disservice to graduate students if they realize that they do not want or need a PhD. We also posit that departure from a graduate program for a graduate student who leaves an unhealthy work environment or an abusive advisor relationship is a success on the part of the student, who should not be labeled a failure, as the word *attrition* may connote. We as faculty can show students we care by legitimizing and hearing their concerns while also showing that we want the best for them, regardless of whether that path involves a PhD.

A culture of care is not equivalent to a lack of rigor, although that mistaken equivalency can be pervasive in academia. Fostering a culture of care to listen to students, sympathize or empathize with their experiences when possible, and coach students through goal-setting and reflective problem-solving if or when they consider leaving can be much healthier than getting defensive, upset, or panicked. A culture of care also does not mean continuing to support students if agreed-upon progress is not being made or if there are conduct issues: It does, however, necessitate due diligence in communicating with students to solve problems before they become larger, and discussing and documenting underperformance or insubordination, such that students have clear expectations about what is or is not happening, why it is a problem and the timeline for managing issues (including clear timelines for the possible scenario of not working with the group any longer). These conversations are difficult but so much more if students are blindsided. We also recommend working with graduate offices to ensure that documentation of performance or insubordination is handled in a transparent, equitable, and caring way to the benefit of the graduate student's professional development.

9 | CONCLUSION

In this study, we employed critical events analysis to understand how a discrete event can be the impetus to consider leaving the PhD while highlighting supporting events that were also important to attrition decision. By classifying the contexts in which the critical events occurred, we note that some critical events are highly unexpected and may occur outside of the university context, like an unexpected job offer or a severe illness requiring time off. However, we also highlighted how seemingly mundane events and very normal encounters, for example, a meeting with an advisor or a conference, can be critical from a student's point of view, serving to illuminate and accelerate other issues in the student's experience. Viewed through the Graduate Attrition Decisions (GrAD) model, this work also highlighted just how connected the various nodes of attrition are, such that a critical event that impacts one node can magnify prior issues that have been affecting seemingly unrelated aspects of a graduate student's experience. Therefore, experiencing a critical event is one way that engineering graduate students begin to consider departure, helping the research community and other invested stakeholders demystify the process of attrition.

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