

Capturing attrition decisions in engineering graduate students using longitudinal SMS data

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Abstract

This research paper reports results from a longitudinal Short Message Service (SMS) text message survey study that captured attrition decisions from engineering graduate students who decided to leave their Ph.D. program or change degree objectives from Ph.D. to M.S. (Master's-level departure). While past research has investigated doctoral attrition across disciplines to identify various factors that influence students' ideas of leaving (e.g., advisor, funding, lack of well-being), departure is often the result of a series of negative experiences that impact students over time, making it difficult to capture in retrospective interview-based studies. To overcome this issue, we captured the experiences of $N = 142$ current engineering Ph.D. students across the US over the course of a year, collecting data three times per week using SMS text message survey methods. After the first year of the study, we captured doctoral departure in a subset of our participants who decided to leave their Ph.D. programs while enrolled in our study. This study is the first to capture and show attrition decisions in action. It combines real-time understandings of stress and participants' decisions to depart. The results are transformative in gaining insight for the monitoring and understanding attrition in higher education.

Introduction, Literature Review, and Theoretical Framing

The rate of attrition in engineering doctoral programs is substantial, with 44% of women and 36% of men leaving their Ph.D. programs, according to the Council of Graduate Schools [1]. The attrition across disciplines and in the US has received attention due to heightened competitiveness within global higher education [2]. Several crises, including financial/economic crises, Covid-19, and systemic racism (the combination of Covid-19 and racism being called the 'dual pandemic' [3]) together have decreased students' certainty regarding pursuing doctoral degrees, resulting in relatively static numbers of women and marginalized racial groups earning doctorates. Further, although international students comprise over 50% of the engineering graduate student population, political tensions around immigration and student visas resulted in downturns in student enrollment. It is well-documented recent economic and pandemic circumstances have decreased enrollment in engineering graduate programs [4], [5].

To explain the reason for dropout in higher education, attrition studies across disciplines investigated factors influencing dropout and why students decide to leave their programs. Causal factors of students' departure at the college level, such as grades, demographic information, satisfaction, perception to programs, support, financial value, and the environment weighed on their intention to leave [6]–[11]. Findings show that students' attitudes, interpersonal relationships, mentality, and intention to leave were important variables in undergraduate and graduate-level of attrition across disciplines.

Studies have captured a sense of socializing between students and communities such as faculty, advisor, PI, cohort, and lab members. In many cases, the advisor-student relationship is significant

in having successful experiences in the program [12]–[15]. Also, students' dynamic within lab engagement—peers and faculty—can provide encouragement and support, preventing isolation. In the advanced stages of doctoral programs, the cultural atmosphere is essential for graduate students to adjust and feel belonging in their programs—especially for minority groups and women in engineering [13]. Discrimination has been reported from these groups due to white and male-dominated environments [16]–[18]. Some papers demonstrated how rapid changes of requirements for doctoral students in preparing for their future career is a reason for the misalignment of students' expectations in the program [19]–[21].

These personal and institutional environments have an impact on engineering graduate students' mental health [17]. Indeed, doctoral students' mental health is a growing concern [17], [22], [23], especially in how the Covid-19 pandemic affected students' in-person attendance and participation in typical academic, social, and professional networking activities, which has impacted how students connect with their peers within their disciplines [4], [24]. This situation is likely to result in disconnection from their academic support [25]. The impact of these recent global dilemmas on the survival of academia reinforces the importance of creating ways to understand students' real-time experiences during these uncertain times.

Understanding the experiences of engineering graduate students and uncovering their rationales for departure from their programs intertwine the atmospheres of the academic environment as well as the experiences of the students. Researchers have investigated the factors from the individual level to the institutional level related to the retention and attrition of graduate students across disciplines [7]–[11], [19], [26]–[28]. Young [26] asserted that isolation in the preparation of the dissertation process is a reason for Ph.D. attrition. This study included Ph.D. students who identified as candidates and all but dissertation (ABD). These students did not have opportunities to socialize with peers or faculty, while undergraduate and M.S. students had more chances to form a connection within their coursework. The impact of isolation resulted in a lack of support. It has been reported that students in limited-residency situations may be afraid to socialize and ask for help from peers or faculty [25]. These studies are valuable in understanding student experiences in doctoral programs, however, there may still be misconceptions remaining that dropping out from doctoral programs is merely a result of personal reasons.

The methods that have been used to explore attrition previously also have some limitations. Previous studies mainly employ interviews or surveys from students who were enrolled in the program, with occasional focus on participants who had left the program at one point (e.g., [6], [7], [10], [11], [27], [29], [30].) These cross-sectional studies cannot show how various factors or decision processes evolve. However, we argue that students' decision-making processes that go into leaving their programs are not spontaneous, spur-of-the-moment occasions. Indeed, Zerbe et al. [31] showed that these decisions to leave the doctorate happen over a period of time, influenced by significant events in students' lives and various experiences within their academic programs. In recent work, Sallai et al. [22], [30] and Zerbe et al. [22], [30] investigated how mental health, well-being, and the presence of critical events also influence attrition. Findings show that critical events were an entry point into the decision-making processes. These studies indicate that earning a doctoral degree does not necessarily mean students' "success." In other words, simply surviving

a doctoral program is not the same as thriving in a doctoral program. In this way, aggregate completion rates do not show how students experience their programs. Because most previous studies are conducted within a short-term period, capturing either snapshots of students' experiences in graduate school or retrospective interviews, there is still a large missing research gap in terms of understanding student experiences as they happen.

To meet this need, we have designed a longitudinal study using SMS text messages to collect real-time data, as reported in prior work [32]. The survey is grounded in prior literature and theory, most heavily relying on the Graduate Attrition Decisions (GrAD) model [28] to encompass a range of individual and institutional factors that affect engineering graduate students particularly. The GrAD model was developed by Berdanier et al. [28] to describe the range of factors influencing engineering graduate attrition decisions. From the point of Expectancy-Value Theory (EVT), the model captures the physical, financial, and psychological costs incurred by graduate students; goals (and changing goals); advisor relationship; support network; quality of life and work (which includes mental health); and perceptions by others. It is these factors that our team has been interested in studying in participants over time. The research questions for the study are:

1. How do engineering graduate students' intentions to persist in engineering Ph.D. programs vary over the course of a year?
2. What factors correlate with engineering graduate students' intentions to persistence decisions?
3. How, if at all, do the experiences of students who choose to leave their Ph.D. programs with or without a master's degree differ from those who successfully graduate or continue to persist in their programs of study?

Methods

The study presented here is part of a funded, IRB-approved 5-year, nationwide study of engineering attrition and Master's level departure and will examine how graduate students decide to leave their engineering Ph.D. programs. Due to the limitations of psychological constructs within cross-sectional studies, it is difficult to observe the changes in students' decision for departure from their graduate programs. To get a broader and more comprehensive understanding of this decision-making process, this study uses a time series approach to collecting data.

Participants and Recruitment. Engineering graduate students were recruited by sending a recruitment email to graduate coordinators and administrators for all engineering departments/programs at each of top 50 engineering Ph.D.-granting universities as per ASEE By the Numbers [33]. Interested participants were given a screening survey, which collected baseline data on graduate experiences, considerations of attrition, and demographics. The results from the screening survey (N = 2,093) are presented in other work (Blinded for review). Participants for this particular study were selected using stratified maximum variation sampling based on time in the Ph.D., gender, race, considerations of departure, and engineering discipline.

Based on prior literature, some attrition from the study was expected. At the end of the survey, there were 142 domestic students (54% women and 45% men), and 18 participants left this study. In the end, the response rate over the year ranged from a maximum of 95% to a minimum of 62%.

Demographic data for the participants is shown in Table 1. The participants who left the study are omitted in the analysis.

Table 1. Demographic information of participants

Characteristics		N (%)
Gender	Woman	77(54.2)
	Man	64(45.1)
	Other	1(0.7)
Race/Ethnicity	Black	12(8.4)
	Hispanic	22(15.5)
	Multiple	27(19.0)
	Asian	41(28.9)
	White	38(26.8)
	Another	1(0.7)
	Prefer not to say	1(0.7)
Ph.D. program stage (years) based on Fall 2021	Early (1~2 years)	60(42.3)
	Middle (3~4 years)	52(36.6)
	Late (>=5 years)	30(21.1)

Survey Deployment and Data Collection. The data presented in this paper represents data collected from the first full year of data collection, from Jan 17, 2022, to Jan 13, 2023. Participants take surveys via SMS text messages sent to their smartphones three times per week (Monday, Wednesday, and Friday), with additional questions asked on Fridays (weekly survey), at the end of each month (monthly survey), and at the end of each semester (Spring, Summer, Fall). We have presented the development of this scale and the decisions to choose questions and timing in prior work [32].

On Mondays, Wednesday, and Fridays, students were asked two main questions answered on a Likert type scale where 1= strongly disagree to 7 = strongly agree: (1) Today, I am confident I will complete my degree objective and (2) Today, the stress I feel is overwhelming. Weekly questions included questions on advisor relationship, satisfaction with quality of life and work, and any stressful events as an open-ended survey response. The full description of survey questions can be found in the Appendix A to this paper. The survey became routine for participants, as surveys were sent at 3 PM (participant local time) every Monday, Wednesday, and Friday to maximize participation. Participants are compensated with a \$10 Amazon.com e-gift card for each month in which participants satisfactorily complete the study (e.g., missing no more than two ‘daily’ questions and no more than one weekly survey) based on our calculations for accounting for missing data.

Data Analysis

The future goal of this project is to generate a predictive multivariate model for graduate attrition using time series analysis, in which it is crucial to understand how variables are correlated and

have characteristics over time such as trend, stationarity, and seasonality [34]–[36]. In addition, the decision-making process regarding degree objectives is extremely complicated and individualized.

To start this process, in this paper, we begin by investigating descriptive statistics. We explored data across meaningful groups of students, starting with the students' "outcomes" at the end of the year. For our analysis, we divided participants into four groups of people; 1) who decided to depart from their program, 2) who changed their degree objective from M.S. to Ph.D., 3) who remained their program, and 4) who graduated with their Ph.D. We used these four categories to consider specific characteristics between individuals and add more descriptive value to the data. These categories aim to capture some of the dominant differences in participant experiences to better understand what is normative for a particular group of students. Because these are real participants, there was no way to sample to achieve equal numbers of participants in each group, which is a real-world limitation. To analyze data, all data were downloaded from Qualtrics into Excel, and then analyzed using SPSS 29. Some degree of missing data and study attrition was expected. As an initial way to investigate overall trends in the data, we calculated means of each survey item across each of the individuals and aggregated those averages within the group to find the average survey item score within each group of participants at each time point.

Results

The analysis for this paper employs data from 142 participants collected in the first year of the study from participants who consistently participated in the survey over the course of a year. In aggregate, through this year of the study $N = 104$ participants (73%) continued in their program and 22 (15%) graduated with their Ph.D. during this year. Our study witnessed $N = 4$ participants (3%) decided to leave their program with no degree over the course of the year, and $N = 12$ participants (13%) changed their degree objective from Ph.D. to M.S., indicating that we did capture the master's-level departure from the Ph.D., a process colloquially known as "mastering out."

Validation of Survey Items. Correlations. Table 2 summarizes the Pearson correlation coefficients, means, and standard deviations. In order to investigate the relationship between items, we calculated bivariate correlations among questions. Except for Q3 and Q15, the correlation coefficients are between -0.80 and 0.8. Therefore, multicollinearity is checked between Q3 and Q15, asking the same construct about advisor relationships. The variation inflation factor (VIF) is 1, therefore, Q3 and Q15 are not overlapped. Q9 (Intention to leave) and Q1 (Persistence) are correlated with all questions but Q18 (Motivation). However, Q2 (Stress) has a weak correlation with Q9 and Q1 ($r < 0.30$). Q9 (Intention to leave) has a strong negative correlation with Q11 (Cost) ($r > 0.6$). Q1 (Persistence) has strong positive correlations with Q5 (Belongingness), Q7 (Quality of life and work), and Q13 (Productivity). Among seventeen items, Q18 (Motivation) has no significant correlation with most items except for Q6 (Quality of life and work), Q17 (Passion), and Q19 (Motivation).

Table 2. Pearson correlation between questions

	Q9	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q10	Q11	Q12	Q13	Q15	Q16	Q17	Q18	Q19	M	SD
Q9 INTENTION TO LEAVE	1																	3.53	1.29
Q1 Persistence	-.54**	1																4.95	1.26
Q2 Stress	.23**	-.27**	1															4.48	1.28
Q3 Advisor relationship	-.46**	.45**	-.28**	1														4.78	1.29
Q4 Support network	-.51**	.38**	-.39**	.71**	1													4.81	1.28
Q5 Belongingness	-.41**	.62**	-.33**	.49**	.53**	1												4.57	1.41
Q6 Quality of life and work	-.57**	.57**	-.30**	.61**	.60**	.73**	1											4.53	1.20
Q7 Quality of life and work	-.40**	.69**	-.38**	.47**	.43**	.74**	.74**	1										4.35	1.25
Q10 Goals	-.52**	.70**	-.38**	.51**	.46**	.56**	.58**	.71**	1									4.32	1.15
Q11 Cost	-.64**	.48**	-.28**	.49**	.52**	.55**	.68**	.47**	.57**	1								3.84	1.44
Q12 Motivation	-.46**	.38**	-.15	.61**	.63**	.61**	.78**	.48**	.52**	.64**	1							4.76	1.22
Q13 Productivity	-.53**	.66**	-.32**	.53**	.49**	.68**	.68**	.75**	.74**	.59**	.53**	1						4.14	1.51
Q15 Advisor relationship	-.36**	.27**	-.10	.82**	.58**	.39**	.50**	.29**	.33**	.43**	.58**	.43**	1					4.58	1.78
Q16 Support network	-.19*	.27**	-.14	.34**	.46**	.25**	.24**	.29**	.29**	.22**	.28**	.28**	.26**	1				5.20	1.30
Q17 Passion	-.46**	.34**	-.09	.44**	.37**	.52**	.64**	.46**	.40**	.49**	.60**	.52**	.42**	.09	1			4.30	1.61
Q18 Motivation	.14	.04	.13	-.07	-.06	-.16	-.19**	-.11	-.06	-.16	-.16	-.14	-.05	-.05	-.21**	1		5.23	1.49
Q19 Motivation	-.33**	.30**	-.01	.35**	.24**	.39**	.53**	.40**	.25**	.40**	.50**	.42**	.35**	.13	.73**	-.24**	1	4.53	1.51

Note: + $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, $|r| < 0.3$: weak correlation, $|r| \geq 0.6$: **strong correlation**, $-0.6 < r \leq -0.3$ or $0.3 \leq r < 0.6$: moderate correlation

Descriptive Statistics and Comparison of Means Across Groups. Table 3 summarizes means and standard deviations (SD). Means and SD are calculated from the means over time of each individual. The group who decided to leave their program has lower means than the other three groups in all survey items except for Q2 (Stress), Q16 (Support network outside of school), and Q17 (Passion). In those specific (Q2, Q16, Q17) questions, participants who have changed their degree objective from Ph.D. to M.S. have the minimum means. This group also has the highest mean for the item asking about intention to leave the program, indicating that the items are performing well to accurately capture attrition decisions.

The group who graduated with a Ph.D. during the course of the year-long survey indicated higher levels of stress than than the other three groups over the course of the year. We assumed that stress factor is highly likely to affect people’s mental health and quality of life and work [37], which can result in negative perceptions regarding their program and experiences. However, this group shows the highest mean in Q1 (Persistence) and the lowest in Q9 (Intention to leave). For students in the final stages of their program, in which they are preparing a doctoral dissertation defense and navigating future work plans influences these items, such that they are sure they will complete their degree despite the stress.

Table 3: Descriptive Statistics for participants based on degree status

	Continuing (N =104)		Decided to leave (N = 4)		Changed to M.S. (N =12)		Graduated with Ph.D. (N =22)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Q9 Intention to leave	3.49	1.12	4.93	1.32	4.40	1.42	3.01	1.60
Q1 Persistence	5.03	1.13	3.07	1.07	4.52	1.38	5.12	1.55
Q2 Stress	4.46	1.30	3.96	1.25	3.94	1.00	4.98	1.21
Q3 Advisor Relationship	4.84	1.23	4.27	1.96	4.43	1.28	4.79	1.52
Q4 Support Network (Inside)	4.90	1.27	4.43	1.52	4.49	1.09	4.59	1.38
Q5 Belongingness	4.67	1.39	3.81	1.20	4.47	1.18	4.26	1.65
Q6 Quality of life and work	4.62	1.17	3.61	1.37	4.21	1.24	4.46	1.26
Q7 Quality of life and work	4.39	1.23	3.44	1.07	4.33	1.17	4.35	1.42
Q10 Goals	4.29	1.07	3.63	1.26	4.48	1.17	4.45	1.48
Q11 Cost	4.00	1.43	2.17	1.00	3.81	1.42	3.41	1.35
Q12 Motivation	4.84	1.20	3.94	1.72	4.66	1.14	4.56	1.29

Q13 Productivity perception	4.12	1.45	2.67	0.82	4.14	1.73	4.49	1.68
Q15 Advisor Relationship	4.66	1.79	3.33	2.08	4.29	1.65	4.55	1.77
Q16 Support Network (Outside)	5.13	1.31	5.42	1.03	4.94	1.32	5.67	1.21
Q17 Passion	4.37	1.51	4.08	2.27	3.50	1.57	4.42	1.93
Q18 Motivation	5.32	1.38	4.42	2.59	4.61	1.64	5.27	1.65
Q19 Motivation	4.56	1.43	3.08	1.50	3.85	1.35	5.03	1.79

Note: Normality assumption was tested.

While there are sophisticated regression methods that can be used to determine significant differences in repeated measures and longitudinal data, for this pass of the data, they are complex. However, following recommendations for simplifying longitudinal data from literature [38], one option is to create summary statistics of the group, averaging the responses over the year to condense the repeated measures data into a single value from each participant, on which traditional statistical tests can be run. This process allows us to get around the multiple measures limitations. After averaging the responses for each individual for each question over the year, we were able to conducted a one-way analysis of variance (ANOVA) to determine whether there were significant differences between the *means* of the four groupings of participants.

Table 4 summarizes the results of the analysis of variance. There were significant differences in Q9 (Intention to leave), Q1 (Persistence), Q11 (Cost), and Q19 (Motivation) for the groups. We performed a post hoc test with Scheffe’s method to examine the difference between groups. In Q1 (Persistence), the “Decided to leave” and “Changed to M.S. groups” are significantly different from the “Graduated with Ph.D.” group, a finding that is obvious but provides some pragmatic validation that our survey items are capturing student decisions. Calculating means over time and across individuals has the advantage of comparing different groups, though the data are limited because it is impossible to recruit participants retrospectively into the study to add more participants within any given group.

Table 4. Comparisons of means with one-way ANOVA

	F	Effect size (η^2)
Q9 Intention to leave	5.034**	0.099
Q1 Persistence	3.93*	0.079
Q2 Stress	2.097	0.044
Q3 Advisor Satisfaction	0.559	0.012
Q4 Support Network	0.781	0.017

Q5 Belongingness	0.954	0.02
Q6 Quality of life and work	1.291	0.027
Q7 Quality of life and work	0.736	0.016
Q10 Goals	0.67	0.014
Q11 Cost	3.01*	0.061
Q12 Motivation	0.966	0.021
Q13 Productivity perception	1.703	0.036
Q15 Advisor relationship	0.661	0.014
Q16 Support Network	1.259	0.027
Q17 Passion	1.131	0.024
Q18 Motivation	1.242	0.026
Q19 Motivation	2.958*	0.06

Note: * $p < 0.05$, ** $p < 0.01$, Homogeneity of variances was tested and fulfilled.

	(I) Degree Status	(J) Degree Status	Mean Difference (I - J)
Q9 Intention to leave	Leaving	Graduated with Ph.D.	1.92*
	Changed to M.S.	Graduated with Ph.D.	1.39*
Q1 Persistence	Continuing	Leaving	1.96*
	Leaving	Graduated with Ph.D.	-2.06*
Q11 Cost	Continuing	Leaving	1.83+

Note: + $p < 0.1$, * $p < 0.05$, ** $p < 0.01$

Time Resolved Data. In order to understand how data fluctuate over time, we present a small amount of the time series data collected over the duration of the year of the survey, based on the significantly different means between the groups presented before. Means across individuals have significant differences and show interesting trends that provide insight to the descriptive and comparative statistics presented as an aggregate of the years' worth of data. The participant answers to Q1 and Q2 about confidence in persistence and stress, respectively, are illustrated in Figures 1 and 2. Figure 1 describes the Q1 question about persistence that was asked Mondays, Wednesdays, and Fridays. The mean values at each time point of the group who decided to leave their programs are spread out the most among the four groups (Continuing group: Mean = 5.03, SD = 0.11 Decided to leave group: Mean = 3.32, SD = 1.03 Changed to M.S. group: Mean = 4.37, SD = 0.45 Graduated with Ph.D. group: Mean = 4.47, SD = 0.66). The group who are continuing Ph.D. programs is generally higher in Figure 1 than the other three groups, except for the mean

values of the group who graduated with a Ph.D. within the first term from Jan 2022 to May 2022. Furthermore, the standard deviation for Decided to Leave group is the highest among the four groups' SD, indicating fluctuations in decisions to depart. These four groups were noted to have significant differences per the ANOVA on the aggregate means over the duration of the year.

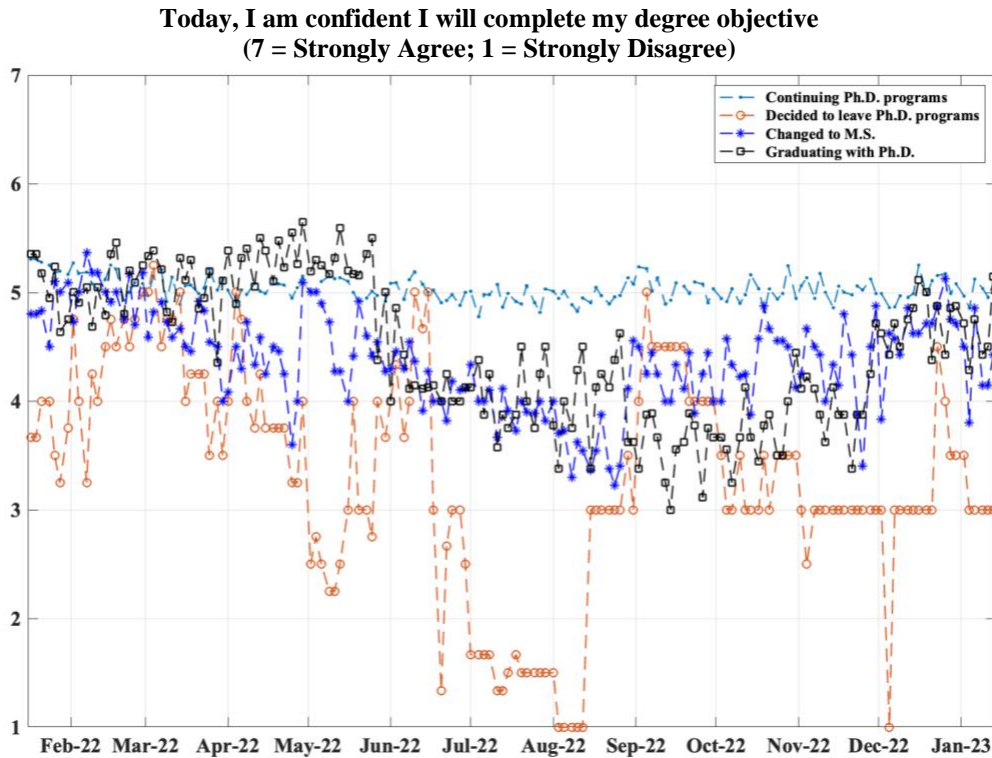


Figure 1. Means of Q1 Persistence across individuals

Figure 2 denotes the answers to the Q2 Stress question, also asked each Monday, Wednesday, and Friday. Interestingly, in aggregate, the four groups did not exhibit significant differences in the Q2 stress variable over the entire year, but the time resolved data show interesting patterns that seem to align with the general changes in academic season (e.g., spring term, summer term, fall term.) These data indicate that more sophisticated time resolved statistics and models need to be used to understand these patterns and reinforce the perspective that aggregate statistics can often hide underlying mechanisms, and also show that the timing of *when the questions are asked* may affect the ways that different students are experiencing their graduate programs. For example, after May 2022, the average stress mean values of ‘Graduated with Ph.D.’ group increased and are higher than other groups, potentially due to looming dissertation and defense deadlines. At this point, although we can qualitatively venture some relationships between leading and lagging indicators of intention to persist (e.g., stress may drop after deciding to leave a program), we have not explored this rigorously to report in this paper. However, we do present the correlations between the items in Table 2, and while those do not indicate directionality, they do show how the responses couple with each other.

Today, the stress I'm experiencing related to graduate school and/or life is overwhelming.

(7 = Strongly Agree; 1 = Strongly Disagree)

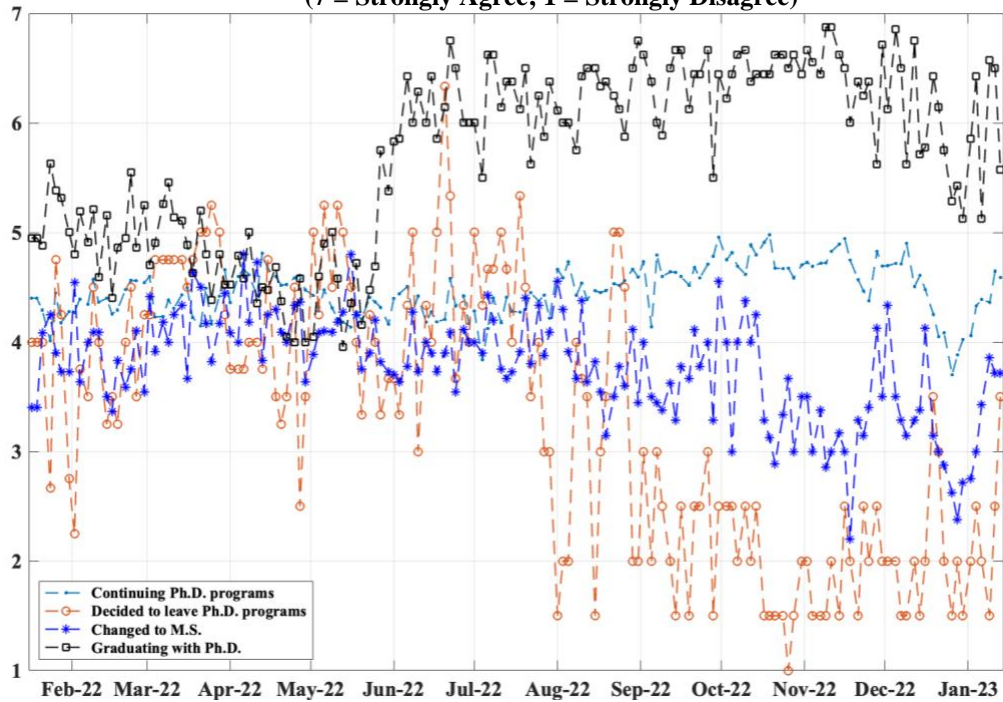


Figure 2. Means of Q2 Stress across individuals

Discussion and Conclusion

There are several important facets of the present study that should be addressed. In answer to the research questions posed near the beginning of this study, we showed that engineering Ph.D. students' intentions to persist oscillate over the course of a year, and that many factors of engineering graduate student thriving and satisfaction are correlated. In the process, we show that the questions that we employ in our study are performing well and indicate which factors may be most important in eventually predicting attrition. We also showed that the persistence intentions for the four groups of students (continuing, left the Ph.D., changed to a M.S., graduated with Ph.D.) differed in aggregate, analyzing the individuals' means over the entire year. However, we also highlight how statistics in aggregate can obfuscate some interesting patterns in student experience. In our study, there were not statistical differences between the four groups' aggregate means in stress over the course of a year, but time-resolved data show very different patterns. In future work, we plan to investigate these data using time series statistics and other computational methods to compare the experiences of the participants in these different groups in more sophisticated and nuanced ways. We also use these findings to highlight for other researchers how the timing of a particular cross-sectional survey may impact responses and results: If a cross-sectional study of persistence and stress had been conducted in May 2022 versus November 2022, there would be very different results, even within the exact same population of students.

Prior literature, especially qualitative work, has elucidated how the decisions to stay or leave are highly intertwined and complicated, and each individual graduate student makes decisions with

respect to how much and what kind of “costs” can and should be incurred in grad school (Blinded for review.) Past work has also discussed mechanisms of socialization for graduate students and the ways in which students develop belongingness over the course of their programs as they progress through formal milestones or more informal ‘threshold concepts’ [39]. However, there are other sources of data that we have that will also be interesting to discuss: Literature shows that for engineering as a highly gendered and raced discipline, students from historically marginalized communities especially struggle (e.g., [18], [40], [41]): For the extended study, we will investigate the effect of demographic traits such as gender, race, or stage in degree programs regarding the attrition, which would have been too extensive for this conference paper. We also note that in future work, we need to consider methodological approaches that can investigate the differences between individuals as well. While the seasonality of the academic year is one way to conceptualize stress and attrition considerations, literature also indicates the myriad individual psychological, sociological, and structural factors affecting graduate students: At the individual level, human behaviors are not dependent on time, and so time resolved models will need to be able to “normalize” data to map trends without using the timescale to compare individuals. In other words, we eventually need to find a way to compare and visualize individuals’ trajectories without month or day of the week being an independent variable that “causes” stress or attrition considerations: Folks could have similar oscillating attrition considerations, but if our methods of visualization and analysis are solely using time on the x-axis, we may not be able to notice the similarities in trajectory.

In conclusion, this research presents a year of surveys conducted via SMS text message methods following N = 142 students over the course of a full year. As demonstrated in [28], the intertwined rationale for leaving, measured by Q9 (Intention to leave), is intertwined with other questions. The results from this study offer a much more nuanced understanding of how engineering Ph.D. students are experiencing graduate school and considering attrition. Further, the correlations, descriptive statistics, and ANOVA presented shows that students who have decided to depart from their programs with or without a master’s degree, persisting students, and those who end up graduating are likely experiencing graduate school differently. This work also is the first that offers a time-resolved understanding of the stress and attrition considerations experienced by engineering Ph.D. students.

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Appendix A. Survey Questions Distributed at Various Frequencies

Distribution Frequency	Theme Assessed	Item
Daily (Monday, Wednesday, Friday)	Degree completion confidence	Q1 Today, I am confident I will complete my degree objective (e.g., MS or PhD).
	Perceived stress	Q2 Today, the stress I'm experiencing related to graduate school and/or life is overwhelming.
Weekly (Fridays)	Advisor relationship	Q3 This week, I am satisfied with my relationship with my advisor.
	Support network	Q4 This week, I feel well-supported by the people I interact with at my university.
	Belongingness	Q5 This week, I feel I belong in my discipline.
	Quality of Life and Work	Q6 This week, I like the work I do as a graduate student. Q7 This week, I am satisfied with the quality of work.
	Stressful events	Q8 Have you experienced stressful events related to graduate school and/or life this week? [Yes/No] Yes-> Could you describe the event(s)? (Text box)
Monthly (Last Friday of Month)	Intention to dropout	Q9 In the past month, how often did you consider leaving your program?
	Goals	Q10 This past month, I felt that I was on the right track to meet my future goals.
	Cost	Q11 This past month, I felt that pursuing an advanced degree was worth the costs (e.g., effort, time, money, psychological costs).
	Motivation	Q12 This past month, I felt what I have studied got along with my values (e.g., curiosity, ambition, success).
Quarterly (December, May, August)	Productivity perception	Q13 In the last four months, I felt successful.
	Advisor relationship	Q15 At this point in my program, I consider my advisor a mentor.
	Support network	Q16 In the last four months, I felt well-supported by people in my network outside the university.
	Passion	Q17 At this point, I consider myself passionate about my research.
	Motivation	Q18 In the last four months, I was motivated to do my research because of external factors, such as external pressures from my PI, advisor, or funding requirements, being afraid of upsetting others, avoiding punishment, or avoiding feelings of guilt. Q19 In the last four months, I was motivated to do my research because of personal internal factors, such as the pleasure or the sense of accomplishment I get from conducting my research.
	Degree status	Q20 Are there any new changes to your degree objectives (check all that apply)? (Options give change of degree choices, including deciding to depart but not formally changing degree.) Q20-1 Which option best describes your graduation? (Options include degree completion, departing with a Masters and departing with no degree).
	Perception by others	Q21 (Survey logic for those who selected an option indicating they are leaving their degree program) I am worried what others will think about my decision to change my degree objective.
	Critical events	Q22 A "critical event" can be defined as an important occasion, event, or milestone related to graduate school and/or personal life that causes a re-evaluation of worldview or goals. Critical events can be either positive or negative. From your point of view, in the last four months, did you experience any "critical events" that affected your degree objectives (e.g., altercations with labmates,

		<p>switching advisors, achieved academic milestones, getting married, having a baby)? If yes, please tell us about any critical events from these four months that affected how you consider your degree objectives. (Open ended)</p>
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