Crossing the Threshold: Improving STEM Graduate Student Education through Project Management Skills Training

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Abstract

Graduates Advancing Professional Skills (GAPS), a National Science Foundation-funded program, aims to bridge the professional skills gap in Science, Technology, Engineering, and Mathematics (STEM) graduate education. GAPS is a one-credit course offered since the Fall of 2020, and it prepared 72 graduate STEM students to implement project management (PM) techniques to enhance their research competencies and adaptation to their future careers in both academia and industry. Our prior studies collected students' immediate feedback from four cohorts during their training, indicating GAPS' effectiveness through the short-term assessment of students' positive transformative project management awareness and application regardless of their intended professional trajectories. The purpose of this study is to further assess the long-term effectiveness of GAPS by surveying alumni 3-24 months after completion and understanding their current PM application status in their professions. To achieve our goal, the threshold concept [17] is implemented to assess GAPS alumni's perceptions of implementing PM techniques into their work by capturing the transformative, integrative, and possibly irreversible characteristics of the threshold concept [17]. Among the 70 alumni contacted, 22 responded to the alumni survey, including 73% of graduate students/postdoctoral students and 27% of industry practitioners. We analyzed their survey responses, and found GAPS's effectiveness in fostering project management skills, with notable preliminary findings: all industry practitioners and the majority of academy group participants acknowledged that GAPS prepared them in succeeding their current profession. More than 80% of industry and academy participants indicated GAPS changed their PM approach. The majority of alumni respondents indicated their shift of PM proficiencies, with very few of them having "low" proficiency levels. Finally, we found more than half of the academy respondents frequently utilize Work Breakdown Structure (WBS) and Critical Path in their work. These results affirm the program's lasting positive effects on participants, underscoring its potential to enhance graduate STEM education by equipping students with essential professional skills for successful careers in both academia and industry. This study advocates for integrating professional skills training in graduate education to better prepare graduate students for success in their current work and future careers.

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Project management (PM) skills- defined as "the process of managing, allocating, and timing resources to achieve a given goal in an efficient and expeditious manner" [1, p.7]- are critically important for any STEM career. These skills frequently are expected of those who seek careers in industry. Undergraduate students may be introduced to these skills if they major in engineering or have internship experiences in industry; however, these skills are rarely taught at the graduate level. Graduate education primarily focuses on developing skills required for the academy (i.e., research, grant writing) and often overlook other skills that are more critical to success in professions in the industry. Over the past decades, students have increasingly been seeking positions outside the academy, opting, instead, to work in the industry [2]. STEM employers seek doctoral and master students who are equipped with professional skills that go beyond what is typically learned in textbooks, but universities often lack resources to train students in these skills [3].

Therefore, given these shifts in the career trajectories of graduate students and the lack of training related to professional skills within graduate education, new strategies for preparing graduate students for their future careers are needed. Our project, Graduates Advancing Professional Skills (GAPS) program, sought to address this need. Funded by the National Science Foundation Innovation in Graduate Education (NSF-IGE), we developed project management training for Science, Technology, Engineering, and Mathematics (STEM) graduate students. Our goals are to support graduate STEM students to thrive in the graduate program and prepare them to implement the PM skills in their future careers.

GAPS is a one-credit pass-fail semester-long course that meets weekly for 50 minutes – 80 minutes [4], [5]. Due to the pandemic, this course was offered virtually from Fall 2020 to Spring 2021 [4], [5]. GAPS shifted from a virtual to an in-person format, which continued from the Fall of 2021 to the present. In total, the course has been offered for seven semesters, and it offers PM training that focuses on the utilization of various tools and concepts, such as the Gantt Chart, Work Breakdown Structure (WBS), Critical Path, etc. [4], [5]. There are a total of 72 graduate students in STEM majors who have completed GAPS. We administered surveys during the first and last week of class to assess students' perspectives of the GAPS course. Our findings illustrated that the course increased students' understanding of the importance of PM skills and that students were more likely to apply these skills to their research and projects since taking the class [4], [6].

Although our initial work indicated that the course was successful in increasing knowledge and use during the semester they were enrolled in GAPS, our current study sought to examine students' use of PM skills months after completing the course. Guided by the threshold concept framework, our project sought to address the research question: What are GAPS alumni's perceptions of the effectiveness of the GAPS program and their current use of PM skills?

Literature Review

Project management is valued by employers [7], specifically in STEM [3]. Research focused on the development and implementation of PM training suggests that integrating PM training into the undergraduate curriculum can be beneficial for prepping their future career [8], [9], [10], [11], [12]. Specifically, some studies highlighted their curriculum designs in helping undergraduate students to gain PM experiences [8], [9], [10], and assess and understand students' learning experiences with PM knowledge [9], [11]. However, there's a lack of studies that were focused on STEM (e.g., software engineering [9], chemical and biological engineering [10]). Castañón–Puga et al. [9] assessed students' user experiences with the Earned Value Management (EVM) simulator, understanding the team members' roles and agile development process to gain the PM experiences. Gilbuena et al. [10] adopt the ethnographic approach to assess how final-year undergraduate students in chemical, biological, or environmental engineering gain professional skills through capstone projects, and they [10] found frequent faculty feedback is essential in enhancing their activities in technical training.

The majority of research on PM skills has been focused at the undergraduate level [9], [10], [11], [12]. Research on PM training at the graduate level has been limited to Master's level education [13], [14]. For example, Do Amaral et al. [13] highlighted Project Management (PM) training within an MBA program in Brazil, utilizing a Problem-Based Learning (PBL) framework to engage students in real-world scenarios. They [13] adopted PBL to enhance PM skills for 1400 master's students who worked closely with teams, faculty, government entities, and corporations. Nowicki et al. [14] introduced a student research project class in the master's program at the Technical University's Faculty of Electronics, Telecommunications, and Informatics in Gdańsk, Poland. This class is designed to help them better prepare for their future careers (e.g., R&D positions, high-tech companies) involving research (e.g., in institutes/universities) and scientific tasks. As a program outcome, students completed 80 research projects, contributing to 11 published research conference papers and scientific journals, and securing one patent, highlighting the importance of engaging with PM training in graduate education.

One study conducted by Ravankar et al. [15] did include doctoral students, but this study did not focus specifically on STEM students. They revealed the applicability and value of PM training, demonstrating that engagement in PM training aligns with graduate students' career aspirations and satisfaction across various fields [15]. Despite these studies, Arditi et al.'s [16] review of civil management and construction master's programs in the U.S., highlighted a notable gap in PM training within this field. Their survey of 21 world-leading universities indicated a lack of PM education, which indicates a significant area for improvement in equipping graduates with essential project management competencies in engineering graduate education.

Considering the increasing trend among STEM students who seek employment in industry sectors upon completion of their studies [2], coupled with there is a clear indication that STEM employers are looking for master's and doctoral students who possess project management (PM) skills [3]. We thus conclude that there is a need for implementing PM training in graduate STEM education [15], [16]. As highlighted by Badiru et al. [1], project management scheduling tools such as Work Breakdown Structures (WBS), Gantt Charts, and Critical Path Method can be effectively tailored for managing research projects and graduate program milestones. We argue

that PM training is not only beneficial for preparing graduate students' future careers but also essential for enhancing graduate students' research efficiency and overall success in their studies. This aligns with the broader recognition of PM skills as critical for both master's and doctoral students succeeding in graduate programs.

Framework

This study employs Meyer and Lands' threshold concept [17] to explore GAPS alumni's perspectives on PM applications to their current profession. Threshold concept "can be considered as akin to a portal, opening up a new and previously inaccessible way of thinking about something" [17, p.1]. Threshold concept [17] has five unique characteristics: transformative (changes in learner's perceptions of the new subject), possibly irreversible (learners could unlikely forget their newly gained knowledge), integrative (learners make connections with learned knowledge to different subjects), possibly bounded (there are constraints within a specific field), and troublesome (challenges in comprehending new knowledge). Cajander et al. [18] suggested integrating the threshold concept [17] into assessing professional skills in engineering education, as stated, "this transformative stage of development and learning is named liminality by Meyer and Land. Liminality in this context can be understood as the period preceding the actual 'crossing' of the threshold." [17, p.8]. For example, students are often exposed to workshops and classes focused on time management. Student can learn strategies for managing their time, but just learning strategies does not change behavior. Students only surpass the threshold when they utilize the strategies in ways that consistently transform their behavior such that their old habits are replaced with more effective ones.

In higher education, the threshold concept [17] has been applied in various disciplines. It has been integrated into social science classes [19], [20], [21], writing [22], [23], computer programming [24], online learning pedagogy [25], physics [26], Civil Engineering [27], and problem-solving interdisciplinary courses [28]. In these studies, researchers applied threshold concept [17] to investigate students' learning journey by exploring its transformative nature [11], [19], [20], [21], [22], [24], [26], [27], [28], troublesome [11], [20], [21], [22], [23], [24], [25], [26], [27], integrative [11], [21], [22], [24], [26], possibly irreversible [11], [21], [29], and bounded characteristics [21]. In this study, we consider PM training as embodying this threshold concept [18], [30] to understand how GAPS helps their perceptions change (transformative) in applying the PM concepts and tools to their work, further underscoring the integrative and possibly integrative nature of their learning [17].

Conceptualizing PM skills as a threshold concept [17] allows us to examine if the GAPS course not only taught students about PM skills but also changed their approach to a project or research. Participating in GAPS changed their approach to project management, which indicates the shift in their PM approach, that is, matching the transformative characteristics of the threshold concept [14]. In addition, we examine the extent to which alumni apply PM knowledge in their current work, which aligns with the "integrative" characteristics of the threshold concept [17]. Further, we focus on the "irreversible" characteristics of the threshold concept [17]. We aim to uncover insights from GAPS alumni on their ongoing application status of PM skills in their work after completing the GAPS. The completion of the course assignments related to gaining

PM knowledge represents the first step in confirming that students both understood and practiced integrating PM tools into their work. Prior research revealed GAPS assisted 19 first-year graduate STEM students in becoming familiar with and using PM techniques (e.g., Lean Concept, Critical Path, etc.) [6]. The consistent finding is further confirmed by Gansemer-Topf et al. [4] study in which students who enrolled in GAPS (pre-survey: N= 46; post-survey: N= 29) increased awareness and applications of PM techniques. Our prior investigations [4] [6] have shown that students participating in the GAPS program successfully incorporated project management (PM) techniques into their work routines. Conducting a survey among GAPS program alumni regarding the current application of their PM skills in their work allows us to present the irreversible aspects of the threshold concept [17].

While prior studies [19], [23], [24], [28], [31] applied threshold concepts qualitatively revealed the immediate results of students' newly gained knowledge, we believe that adopting a quantitative method [20], [26], [32] allows us to further investigate how GAPS alumni absorb and apply PM skills to their current profession. This study is achieved by examining their perceptions of GAPS and their current PM application status to better understand the effectiveness of GAPS. Therefore, by conducting online surveys with alumni after they finish the GAPS course and further engage in different academy/industry roles, we can assess alumni's perceptions of the GAPS's impacts over time. To assess GAPS alumni's perceptions, the descriptive statistic is primarily utilized to answer our research question. By comparing the percentages of different survey categories, we provide evidence of the transformation of learned knowledge into continuous practices, reflecting the threshold concept [17]'s transformative, (possibly) irreversible, and integrative nature.

Method

This study was part of a larger NSF-funded study examining the impact of the GAPS course in developing project management skills. Our previous efforts to assess the effectiveness of the course focused on disseminating surveys to students before and immediately after the course to evaluate students' interests and knowledge regarding PM skills [4] [6]. Our findings demonstrated that students perceived the course to be useful in developing their PM skills [4] [6]. In this study, we disseminated a similar survey in Fall 2023 to the same group of students who participated in the GAPS program from Fall 2020 – Spring 2023 (N=72). Aligned with our threshold concept framework, we were interested in examining students' perceptions of the value and use of PM skills several months or years after completing the course.

Participants & Recruitment

We disseminated the survey to all students who had participated in GAPS from Fall 2020 to Spring 23 (N=72). Most GAPS students came from engineering disciplines: Material Science and Engineering (29%), Chemical and Biological Engineering (24%), Industrial and Manufacturing Systems Engineering (11%), Civil Construction and Environmental Engineering (10%), Agricultural and Biosystems Engineering (8%), Mechanical Engineering (6%). but other STEM disciplines represented included: Food Science and Human Nutrition, Biology and Environmental Science, Horticulture, and Physics.

The majority of participants were doctoral students (88%). We contacted students via their institutional email or through LinkedIn. We obtained valid email addresses for all but two participants.

Data Collection

We distributed the survey to GAPS alumni in Fall 2023. The alumni survey consisted of 12 questions that gathered GAPS alumni's demographic information (i.e., employment area, current specialization or major in graduate school, gender, and ethnicity), perceptions of the GAPS program in developing their professional skills, and perceptions of their proficiency and frequency of application of PM skills.

We analyzed data based on the response survey responses, which include five-point Likert scale questions ranging from 'Strongly agree' to 'Strongly disagree.' We also evaluated GAPS alumni's self-assessed PM proficiency and frequency of PM skills and concepts based on a three-level self-assessment scale ('low,' 'medium,' 'high'; 'never used,' 'infrequently used,' 'frequently used,' respectively).

Data Analysis

We engaged in simple descriptive statistical analysis, calculating the percentages of each response. Because we were curious about the effectiveness of the GAPS program for students in different career trajectories, we also analyzed data based on those who were working in the industry and those in the academy. In this study, we represent the distribution of GAPS alumni's responses to provide evidence of the course's long-term impact. This analysis will uncover alumni's perceptions, demonstrating whether GAPS significantly transformed their PM knowledge and their application status to their work.

Results

Of the 70 participants we contacted, we received 22 responses, a 31% response rate of those that responded. Of those who responded, 82% were in engineering, and 14% were in other STEM fields. One respondent chose not to disclose their current area of specialization. Sixteen respondents (73%) were graduate students/postdoctoral students, and six (27%) were working in industry.

This section presents the results from 22 GAPS alumni's responses to their perceptions of the GAPS' effectiveness. We further analyzed into two groups: academy and industry. The academy group represents graduate students and postdoctoral students, and the industry group comprises alumni who are employed outside of a college or university.

Overall, our findings indicate that the GAPS program was effective in preparing students to implement PM skills. All GAPS alumni who are working in industry (100%) and almost all of those in the academy (87.5%) benefited from the GAPS in gaining an understanding to integrate the PM knowledge into their current work. Furthermore, 81% of the academy group of

participants and 83% of industry practitioners reported participating in GAPS altered their approach to managing their projects.

Table 1 indicates GAPS alumni's self-assessed proficiencies in utilizing PM tools and concepts, and Table 2 indicates the frequency with which alumni utilize the tools. Both academy group and industry group participants rated their proficiency as "high" in applying Critical Path to their profession, 66.67%. Over half of the academy group participants rated themselves as having "high" proficiency in Work Breakdown Structure (WBS) (56.25%) and Gantt Chart (53.33%). Half (50%) of industry practitioners rated their proficiency as "high" for Lean Concept. Notably, results show GAPS alumni rated their proficiency as "low" between 0% and 20% with given PM concepts and skills.

Academy group participants mostly frequently apply Critical Path (56.25%), WBS (53.33%), and Project Charter (40%) in their current work. Industry alumni reported they infrequently apply Lean Concepts (66.67%) and Project Charter (50%) to their work. Kanban Board emerged as the least tool among both groups of GAPS alumni, indicated by 66.67% of the academy group participants and 50% of industry practitioners that they "never used" it.

TABLE 1. Percentages of Responses for GAPS Alumni (N=22) Project Management Proficiency

PM Concepts/Skills	Professions	Low	Medium	High
Kaban Board	Academy	20.00%	60.00%	20.00%
	Industry	0.00%	66.67%	33.33%
Gantt Chart	Academy	13.33%	33.33%	53.33%
	Industry	33.33%	16.67%	50.00%
Work Breakdown Structure	Academy	6.25%	37.50%	56.25%
	Industry	0.00%	66.67%	33.33%
Project Charter	Academy	12.50%	56.25%	31.25%
	Industry	16.67%	50.00%	33.33%
Lean Concept	Academy	20.00%	40.00%	40.00%
	Industry	0.00%	50.00%	50.00%
Critical Path	Academy	0.00%	33.33%	66.67%
	Industry	0.00%	33.33%	66.67%

TABLE 2. Percentages of GAPS Alumni's (N=22) Frequency of Applications with PM Concepts and Skills.

PM Concepts/Skills	Profession	Never used	Infrequently used	Frequently used
Kaban Board	Academy	66.67%	26.67%	6.67%
	Industry	50.00%	16.67%	33.33%
Gantt Chart	Academy	26.67%	46.67%	26.67%
	Industry	33.33%	33.33%	33.33%
Work Breakdown Structure	Academy	33.33%	13.33%	53.33%
	Industry	33.33%	33.33%	33.33%
Project Charter	Academy	40.00%	20.00%	40.00%
	Industry	33.33%	50.00%	16.67%
Lean Concept	Academy	50.00%	35.71%	14.29%
	Industry	16.67%	66.67%	16.67%
Critical Path	Academy	37.50%	6.25%	56.25%
	Industry	50.00%	33.33%	16.67%

Limitations

Our study is not without limitations. Although our response rate of 31% is consistent with most online survey rates, we acknowledge that survey response bias may be present [33]. Most of our survey respondents are still students in graduate school, which limits our understanding of alumni who pursued careers as faculty in the academy. Further, to preserve the anonymity of our students and given the small population, we did not disaggregate data into subgroups, (e.g., participant's cohort, race/ethnicity, gender). This lack of nuance limits our ability to understand if our results are consistent across all student populations. Additionally, the descriptive statistics limited us in understanding the reasons behind students' survey responses on PM proficiencies and the application frequency of PM skills and concepts. Therefore, future studies will include focus group interviews with GAPS alumni to help better understand the comprehensive picture of GAPS' impact. Finally, the results were based on self-reported data, which suggests that discrepancies could exist between participants' perceptions and their actual practices in applying the PM skills to their work. However, self-reported data can still be reliable [34]. Self-reported trustworthiness can be enhanced if the survey is carefully designed and specifically employs multiple data sources [34], which suggests the future study involves conducting focus groups with alumni to understand better their perceptions regarding the GAPS's effectiveness. GAPS alumni engaged in different activities such as finishing the class, participating in discussions, completing assignments, and integrating PM tools, evidencing their achievement in GAPS. This engagement suggests that their perceptions are shaped by their active involvement [35], [36]. Such evidence adds to the credibility of this study and reinforces the necessity of adding PM education to graduate curricula.

Discussion

Through GAPS alumni's perspectives, the industry practitioners and the majority of the academy group of survey respondents affirmed GAPS demonstrated effectiveness in preparing them to succeed in their current professions in the academy and industry.

Our investigation indicates a significant shift in PM approaches among GAPS alumni regardless of their place of employment. Students who completed the course indicated that the GAPS changed their approach to managing their projects. We see this shift of perception as "transformative" in the threshold concept [17]. In addition, our previous study [4] showed a significant increase in the PM proficiency level of GAPS students from different intended career paths: industry, research (national labs), and faculty. This study reveals a similar pattern in how GAPS alumni assess their PM proficiencies, with very few indicating "low" proficiency levels. We characterized this change in self-rated PM proficiencies as "transformative" [17], indicating students reached a threshold in their gained PM knowledge.

Our prior study [4] indicated GAPS students increased their awareness and usage of PM concepts and skills. This study extends our previous work by emphasizing the continued PM applications to strengthen their skillsets and current professions. This alignment indicates the integrative aspects of the threshold concept [17]. All industry practitioners and most participants from the academy acknowledged the PM skills they gained from GAPS prepared them for their current roles. Further, our findings also indicated the frequency with which GAPS alumni apply PM tools and concepts in their work, demonstrating the alignment with the integrative aspect of the threshold concept [17]. This finding indicates that PM skills are relevant to GAPS alumni's needs and further PM tools and concepts can be integrated into their current work.

We noticed most GAPS alumni rated their PM proficiencies as "high" in applying Critical Path to their work. Further, we found more than half of the academy group of participants frequently incorporated WBS and Critical Path to their research and projects. As previously highlighted with our new finding, more than 80% of participants from both the academy and industry indicated that enrolling in GAPS changed their original way of PM approaches. Incorporating this new finding into our prior research [4] [6], we align this evidence with the threshold concept's characteristic of being "possibly irreversible" [17], suggesting the PM knowledge and skills they gained from GAPS tend to persist over time, given alumni's continued PM application status and frequency of use in PM techniques. The goal of this study is to highlight alumni's (learners') perspectives on their self-assessed PM proficiencies through the threshold concept framework, we argue these findings collectively serve as evidence of the GAPS's effectiveness in PM training.

Based on the interpretation of the threshold concept [17], we suggest GAPS is effective in preparing graduate STEM students to succeed in their programs and post-graduation careers and leading students across the threshold of gaining PM skills through alumni's perceptions shifts after engaging with the class, and further apply PM into their current profession. We suggest GAPS is a tool to facilitate graduate STEM students to develop their PM skills. When students retain what they have learned from the GAPS and continue to apply it to their work, PM skills can become habits to support their professional goals.

The anticipated long-term outcome of this program is the efficient use of time and resources, alongside narrowing the competency gap between graduate studies and professional career development. Furthermore, the program fosters a culture of collaborative learning and encourages communication among students from diverse academic backgrounds. It provides an environment for students to exchange and refine their thesis research with peers from other disciplines. By equipping GAPS students with skills to optimize their productivity in both time management and project execution, we facilitate their smoother transition to future professional roles. Importantly, the scope of this program is not confined to STEM fields, it can be applicable across all areas of specialization. Integrating professional skill training with thesis research not only helps gain faculty buy-in but also provides opportunities for students to better retain the skills.

Conclusion

This study indicated that students who completed the GAPS course and responded to a post-survey three months to two years after completing the course felt they had gained PM knowledge and recognized the relevance of PM skills and concepts. These preliminary findings also indicate that these skills prepared them for their current professional roles. Since the respondents are either ongoing students or relatively new professionals, they are only able to assess their current needs, and there is a potential that these PM skills will be fundamentally relevant throughout their academic and professional careers. Recognizing the need to better prepare graduate STEM students for careers in both academia and industry, GAPS is continuously making curriculum and instructional improvements through the use of survey collections and focus group interviews with current GAPS students and alumni. PM employs iterative processes and GAPS models this approach as well to offer better support in preparing graduate STEM students in their post-graduation pathways. We suggest that making improvements to bridging the GAPS into graduate education can not only aid graduate students to successfully complete their thesis research and prepare for their future careers but also contribute to strengthening the future STEM workforce by providing PM training to both industry and academy career individuals.

GAPS provides an enriching class environment that gives students a space to gain PM knowledge and engage with their peers. Our past and current work presented students' transformative shifts in PM knowledge and PM integration into their work. We continuously seek to answer the question of GAPS effectiveness by understanding students' and alumni's perceptions about the PM training and current application status. The ongoing inquiry will help us to prepare graduate students better to succeed in their education and career goals through PM training.

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