Evaluating the Implementation of Project Management Skills Training within STEM Graduate Education

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Implementing Project Management Skills Training Through Thesis Research Within STEM Graduate Education

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Science, Technology, Engineering, and Mathematics (STEM) graduate education traditionally has focused on developing technical and research skills needed to be successful in academic and research settings. In the past decade, however, STEM graduate students increasingly have sought positions in the industry [1]; a recent study by Sherman et al. [2] found that non-academic industry jobs were the most preferred career choice for STEM doctoral students. Despite this preference, graduate education has yet to adapt to better prepare students for their industry positions; a significant portion of students need critical professional skills, such as project management (PM), needed to be effective leaders in these non-academic environments [3-9]. Although a required skill in the industry, these professional skills also can significantly enhance future careers within research and the academy.

We sought to address the lack of PM training in graduate education through our Graduates for Advancing Professional Skills (GAPS) program funded by NSF-IGE (National Science Foundation - Innovation in Graduate Education). One major component of the project is developing a one-credit course, *Introduction of Project Management for Thesis Research*. The course has been offered each semester since Fall 2020 with a total enrollment of 75 students with different degree specializations. During the course, students learned PM skills and then applied these skills directly to their current research projects (thesis). Applying PM skills to research benefits both the student and their research team by improving time management, task completion, and communication. Ultimately, we anticipate that PM skills will increase students' likelihood of completing their degrees and equip students with transferable knowledge for their future work.

To assess the effectiveness of the course in meeting our goals, we developed a comprehensive evaluation plan that included pre- and post-class surveys. These pre- and post-surveys asked students to rate their familiarity with and use of PM skills. In this paper, we provide a detailed description of the course and highlight the results of the pre-and post-surveys that focused on the question, "What influence did the course have on students' knowledge and application of PM skills?"

Course Overview

The GAPS course (MSE 580x), Introduction of Project Management for Thesis Research, aims to improve graduate STEM students' efficiency in completing their thesis research and projects by adapting the PM skills and concepts. This one-credit, satisfactory-fail semester-long course is offered once a week for 50 - 80 minutes. Students learn PM processes such as Work Break Down Structure and Critical Path and tools like the Project Charter and Gantt Charts. Although the course's primary focus is PM skills, throughout the semester, students have the opportunity to develop other skills such as communication, reflective writing, and interviewing skills. Beyond existing knowledge, students are expected to integrate the learned skills and concepts into their research work/projects. Students complete weekly assignments and one team presentation at the end of the course.

Learning Outcomes

MSE 580x was developed to achieve the following five specific learning outcomes.
As a result of this course, students will be able to:

1. Develop a project charter for the thesis research
2. Devise a communication plan and use scheduling software (Microsoft Project (MSP))
3. Create Gantt charts
4. Utilize the Critical Path Method (CPM) for the thesis research
5. Identify challenges and opportunities associated with PM in thesis research.

Course Description and Outline

The course blends lectures, panel discussions, small and large group activities, reflection, community building, and presentations. The project principal and co-principal investigators teach lectures, and STEM field academy experts and industry professionals are invited as guest lecturers to share their insights in the PM area. The last 15-30 minutes of each class are dedicated to interactive activities to have students apply their skills, build community, and develop professional networks.

Course Expectations and Assignments

Students are expected to attend class weekly and complete homework assignments: discussion posts on selected course topics; creating reflective writings; creating Project Charter, Gantt Chart, Critical Path, and WBS for their thesis/research projects; completing Clifton Strengths test and individual career assessment before attending the class. For weekly classes, students participate in small and large group discussions to gain an understanding of course topics. Following the 50 min lecture, students participated in the post-lecture activities such as small group peer reviews for reflective writing, discussion of the application of PM skills, and Q&A with guest lecturers (see Table 1).

Table 1. Course Content

Week	Course Topic	Learning Activity
1	Introduction	Icebreaker game
2	Project Charter	Building project charter for thesis/ research projects
3	Clifton strength	Identifying personal strengths
4	PM software tools	Integrating different PM tools for thesis/research projects
5	Reflective writing	Peer review of prior reflective writings
6	Communication strategies	Communication drawing activity
7	Work Breakdown Structure (WBS)	Build WBS for thesis/research projects
8	Critical Path and Lean Concept	Build Critical Path related to thesis/research projects
9	Inclusion in project management	Q&A and reflection discussion
10	Interview and resumes	Mock interview
11	Individual career development plan	Peer review
12	Evaluating and terminating projects	Peer review
13	Time management and work-life balance	Peer review
14	Students' team project presentations	Peer review
15	Students' testimonial video recording & focus group interview	

Course Adaptations

We have made several changes to the course over the six semesters. During COVID-19, the course was offered online in Fall 2020 and Spring 2021. An active learning approach was adapted to teach this course, where straight lecturing was blended with group discussions. We gave synchronized online Zoom lectures and engaged students with discussions using breakout sessions.

Beginning Fall 2021, classes were held in person. The semester-long course meets weekly for 50 minutes. In Fall 2020 the course was offered online for 50 minutes per week, and class time primarily included lectures and demonstrations. In Spring 2021 we added 15-30 minutes of optional time for discussion following the lecture and demonstration. Once COVID restrictions were lifted, we provided food or snacks during these optional activities. Each semester we solicited feedback from students on the positive aspects of the course and suggestions for changes. Students consistently mentioned that the most valuable aspect of the course was the

time spent discussing the content and getting feedback on their plans. Therefore, in Fall 2022 we expanded the class from 50 to 80 minutes, integrating more lectures with discussions. Originally, we kept all course materials and students' assignments in Microsoft Teams. Because this platform was commonly used in industry, we wanted students to experience its benefits and limitations. Although it exposed students to the tool, it was not an effective classroom management tool. Therefore, in Spring 2023 we developed a course page through Canvas, the university's learning management system. This tool provided one place for students to submit assignments; the discussion board tool on Canvas was used to build community through responses to weekly prompts.

Enrollment and Recruitment

The GAPS course has been offered each fall and spring since Fall 2020, with 75 students participating. Cohorts have ranged from eight students in Fall 2020 to 16 students in Spring 2023. Most students were in the first three years of their graduate program, with approximately 25% each in years 1- 3; another 25% had been in the program for four or more years Students represented 12 different majors (see Table 2).

Table 2. GAPS Course Students' Majors (n=75)

Students' majors	**Students (n=75)**
Materials Science and Engineering	32%
Chemical and Biological Engineering	23%
Industrial and Manufacturing Systems Engineering	11%
Agricultural and Biosystems Engineering	9%
Civil, Construction, and Environmental Engineering	9%
Mechanical Engineering	5%
Food Science and Human Nutrition	4%
Electrical and Computer Engineering	1%
Physics and Astronomy	1%
Aerospace Engineering	1%
Horticulture	1%
Computer Science	1%

We recruited participants in several ways. We emailed department chairs and directors of graduate education explaining the program and asking them to forward the information to their students. PIs discussed the program at their department orientation events. Right before the beginning of each semester, a workshop was hosted to explain the purpose of the course. In addition, we thus far have invited 18 successful professors, working professionals, and alums as panelists to discuss their experience of PM skill development with students. Our workshop attendance numbers ranged from 30 to 60 and served as an excellent recruitment mechanism. We usually see a boost in enrollment after the workshop.

At the end of each semester, we also created testimonial videos to showcase what students learned from the GAPS course and the benefits of the course. These videos were then promoted to departments and at our workshop.

Evaluation

The evaluation for the GAPS project was informed by the pragmatic evaluation paradigm [10]. As the name implies, the pragmatic paradigm requires that the evaluation be "practical" or "pragmatic" and therefore requires methods that best address the program's aims. The course aimed to increase students' knowledge and use of PM skills; therefore, we administered pre and post-course surveys to students in each cohort using Qualtrics. The surveys asked students to rate their familiarity and usage of PM skills. Students completed the pre-course survey in the first two weeks of the semester and the post-course survey during the final week of the semester. The surveys contained Likert-style questions asking students to rate their knowledge of specific PM skills on a scale of 1 – 5 and then rate how frequently they use these skills. Student participation was voluntary and anonymous.

In the pre and post-surveys, students indicated their post-graduation plans and were asked to rate their project management skills (i.e., low, medium, high), their familiarity with specific concepts/skills, and their use of PM skills. For the latter, students were asked to rank their level of agreement (disagree, somewhat disagree, either agree or disagree, somewhat agree, and agree) to specific statements such as “I am familiar with LEAN concept technique” and “I have used LEAN concept techniques in my research/thesis project.”

We first calculated the number and percentage of responses for each question and then conducted Mann-Whitney U tests to compare differences between pre and post-survey responses. We chose the Mann-Whitney U test instead of a t-test as the data we analyzed were ordinal and not continuous and also to account for the non-normality of data and smaller sample size [11].

Limitations

Several limitations need to be considered. Because we chose to have the students complete the survey anonymously, we were not able to examine individual students’ familiarity and use of PM skills; therefore, it is not clear if all students increased their knowledge and use or if there were differences by major, future career plans, etc. Although the quantitative data allows us to determine that, on average, students’ use and familiarity have increased, we have little data to indicate how or why. Our future work, which analyzes data from focus groups with students, will provide additional insights into the impact of this class.

Results

Our results are based on the pre-and post-surveys from four semesters: Fall 2020 – Spring 2022. Of the 46 students enrolled in the course, all completed the pre-survey assessment, and 29 (63%) completed the post-survey assessment. Of the students who completed the pre-survey, 46% stated they were looking for employment in industry, 26% were looking for employment doing

research, 15% were seeking a faculty position, 2% were seeking a postdoctoral position, and the other 11% indicated "not sure" or "other."

Students rated their proficiency with, familiarity with, and use of PM skills at the beginning and end of the semester. At the beginning of the semester, 6.5% of students rated their proficiency as high, 52.1% as moderate, and 41.3% as low. At the end of the semester, the percentage of students rating themselves as high and moderate increased to 13.8% and 82.8%, respectively; the percentage of students who rated themselves as low dropped to 3.5%. Table 3 illustrates the percentages of students based on their intended career path. In the pre-and post-surveys, a higher percentage of students interested in a career industry ranked their proficiency as "high" than those in other career paths. In the post-survey, all students interested in careers in research or faculty positions rated themselves as "moderate," which more than doubled the percentage of students who ranked themselves as "moderate" in the pre-survey. Interestingly, a higher percentage of students interested in a faculty position ranked themselves as having "high" proficiency in the pre-survey but not in the post-survey. All students interested in industry, research, or faculty careers rate themselves as "high" or "moderate" in the post-survey.

Table 3. Percentages of Responses for Pre (N=46) and Post (N=29) Project Management Proficiency by Intended Career Path

Intended Career Path	High	Moderate	Low
Pre Survey			
Industry	9.52	61.9	28.6
Research	0	41.7	58.33
Faculty	14.3	42.7	42.7
Other	0	50	50
Total	**6.52**	**52.1**	**41.3**
Post Survey			
Industry	25.0	75	0
Research	0	100	0
Faculty	0	100	0
Other	16.67	66.7	16.7
Total	**13.8**	**82.8**	**3.5**

Students indicated their level of agreement with statements about their familiarity with certain aspects of PM and their use of the skills. We condensed the five categories (agree, somewhat agree, neither agree nor disagree, somewhat disagree, and disagree) into three categories for this analysis. Table 4 provides the pre and post-survey results of these responses. Pre and post-survey results illustrate that the GAPS course increased students' familiarity with and usage of PM skills and tools. For example, in the pre-survey, 28% of respondents agreed or somewhat agreed that they used PM skills in their research. In the post-survey, 93% agreed with this statement. In the pre-survey, students noted they were least familiar with LEAN concepts, Critical Path, and challenges of using PM skills. They were most familiar with the benefits of PM skills, applying PM skills in research, and developing a communication plan. In the post-survey, over 85% of

students indicated they were familiar with aspects of PM. A lower percentage of students agreed that they used a communication plan and Critical Path (75.9%), with the fewest indicating using LEAN (62.5%).

Table 4. Percentages of Pre (N=46) and Post Survey (N=29) Responses for Familiarity and Use of Project Management Concepts

Variable	Agree/Somewhat Agree	Neither Agree/Disagree	Disagree/Somewhat Disagree
PM Techniques (Familiar)			
Pre	26.1	23.9	50
Post	93.1	6.9	0
PM Techniques In Research (Familiar)			
Pre	34.8	21.7	43.5
Post	86.2	10.3	3.5
PM Techniques in Research (Used)			
Pre	28.3	13.0	58.7
Post	93.1	6.9	0
Communication Plan (Familiar)			
Pre	30.4	23.9	45.7
Post	93.1	6.9	0
Communication Plan (Used)			
Pre	26.1	19.6	54.4
Post	75.9	20.7	3.5
LEAN Concepts (Familiar)			
Pre	15.2	6.5	78.3
Post	89.7	6.9	3.5
LEAN Concepts (Used)			
Pre	2.2	13.0	84.8
Post	62.1	24.1	13.8
Critical Path (Familiar)			
Pre	15.2	4.4	80.4
Post	93.1	6.9	0
Critical Path (Used)			
Pre	6.5	13.0	80.4
Post	75.9	13.8	10.3
Challenges (Familiar)			
Pre	17.4	23.9	58.7
Post	96.6	3.5	0
Benefits (Familiar)			
Pre	39.1	17.4	43.5
Post	96.6	3.5	0

We then conducted tests of significance using Mann-Whitney U tests (see Table 5). There were significant differences between students' pre and post-survey responses. Overall, students were significantly more familiar with and used PM skills at the end of the GAPS course. These data consistently show that the course has significantly improved students' awareness and familiarity with PM skills. In addition, students also start to apply the learned skills to their research activities.

Table 5. Results of Pre and Post-Survey Comparisons of Familiarity and Use of Project Management Concepts

	Pre (N=46)		Post (N=29)		*U*	*p.*
Variable	*M*	*SD*	*M*	*SD*		
Familiarity With						
PM Techniques in Research	2.87	1.26	4.31	.81	1088	.00***
Communication Plan	2.72	1.28	4.38	.62	1143	.00***
Lean	1.93	1.24	4.21	.73	1206	.00***
Critical Path	1.78	1.21	4.34	.61	1239	.00***
Challenges	2.24	1.23	4.48	.57	1241	.00***
Benefits	2.76	1.43	4.45	.57	1116	.00***
Used						
PM Techniques in Research	2.54	1.35	4.48	.63	1163	.00***
Communication Plan	2.50	1.33	3.97	.91	1068	.00***
Lean	1.63	.88	3.69	1.07	1218	.00***
Critical Path	1.70	1.01	3.79	1.05	1196	.00***

****p*.<.001

Conclusion

To ensure a qualified and effective STEM workforce, STEM graduate education must train students with the skills necessary for success. Most graduate programs focus primarily on developing research skills but overlook critical professional skills needed in STEM professions. Our pre-survey results illustrated that most students in the GAPs program had little previous exposure to PM skills. Those students interested in a career in industry rated themselves higher than students in other intended career paths, but even for those not interested in industry, almost 1/3 of the students rated themselves as "low" in PM skills. Almost all students rated themselves as moderate or high at the end of the semester. These results suggest that the course successfully provided PM training regardless of career path.

The GAPs program began in the Fall of 2020 in the midst of COVID. The 50-minute course was offered online, with most time spent on lectures related to PM skills. After the first semester and based on student feedback, more time was provided for class interactions and discussions. These opportunities enriched the student experience as students could begin to share how to apply skills to their research with one another. The reflective writing activities also provided important opportunities for students to reflect on their work, which, in turn, can improve performance [12].

Similar to recent reports on the career aspirations of STEM graduate students, many GAPS students intend to seek a position in industry or research after graduation. A much smaller percentage plan to seek a faculty position or postdoctoral position. Teaching professional skills such as PM skills in graduate school addresses the gap in skills training for those seeking future positions outside of the academy while also providing them valuable skills that can be used to support their progress toward degree completion.

The survey results provide a view into students' familiarity and use of PM skills immediately following exposure to course content. Our future work involves surveying GAPS program alumni to understand the extent to which they continue to use and value PM skills in their future careers. Feedback from these surveys can also be used to improve the course.

Although PM skills can be taught, their real value is in the application and transferability of these skills. Our findings suggest that the GAPS course creates an innovative and effective solution to achieve these goals. By integrating with the required independent research in all doctoral programs, our GAPS approach is effective and relatively straightforward to adopt. Our results can inform the improvement of graduate education beyond STEM and ultimately prepare graduates for their future careers in both academia and industry.

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