Engineering Educators Bringing the World Together
2025 ASEE Annual Conference & Exposition
Palais des congrès de Montréal, Montréal, QC • June 22–25, 2025
Paper ID #47692

Empowering Professional Skill Training for STEM Graduate Students Through Active Learning and Inductive Teaching

Jemimmah Namodi, Iowa State University of Science and Technology

Jemimmah Namodi is a PhD student in Higher Education at the School of Education, Iowa State University. She earned her MBA from Kenyatta University and a Master of Science in Student Affairs from Missouri State University. Her research interests focus on rural populations, emphasizing their educational experiences and pathways in higher education.

Dr. Ann M Gansemer-Topf, Iowa State University

Ann Gansemer-Topf is Professor and Director of the School of Education where she oversees undergraduate and graduate programs in education. She has expertise in the scholarship of teaching and learning, assessment, student success and student affairs leadership.

Dr. Gül E. Kremer, University of Dayton

Gül E. Kremer received her PhD from the Department of Engineering Management and Systems Engineering of Missouri University of Science & Technology. Her research interests include multi-criteria decision analysis methods applied to improvement of products and systems. She is a senior member of IIE, a fellow of ASME, a former Fulbright scholar and NRC Faculty Fellow. Her recent research focus includes sustainable product design and enhancing creativity in engineering design settings.

Dr. Qing Li

Education Virginia Tech, Blacksburg, VA Ph.D., Statistics, 2015 Dissertation: Change-Point Detection in Recurrent-Event Context. Advisor: Dr. Feng Guo, GPA: 3.9/4.0

University of Rochester, Rochester, NY M.S., Electrical and Computer Engineering,

Prof. Shan Jiang, Iowa State University of Science and Technology

Dr. Shan Jiang is an Associate Professor in the Materials Science and Engineering department at Iowa State University. He earned his Ph.D. from the University of Illinois at Urbana-Champaign and completed postdoctoral research at MIT. Prior to his academic career, Dr. Jiang worked as a research scientist at Dow Chemical Company, focusing on coating materials. Drawing from his industry background, he founded the Graduates Advancing Professional Skills (GAPS) program, which is supported by NSF IGE funding to enhance professional skills training for STEM graduate students.

Empowering Professional Skill Training for STEM Graduate Students Through Active Learning and Inductive Teaching

Abstract

The Graduates Advancing Professional Skills (GAPS) program, funded by the National Science Foundation, supports professional skills development in STEM graduate education. In traditional STEM curricula, technical knowledge is often prioritized, while key competencies such as project management, communication, and teamwork are frequently overlooked. This imbalance in STEM education can impact graduate students' preparedness for various career paths in both academia and industry. GAPS course design combines active learning and inductive teaching methods, enabling students to apply professional skills directly to their thesis research through community-based experiential learning. In-class discussions, online forums, and peer feedback also facilitate collaborative problem-solving and reflective engagement.

In this study, GAPS was used to evaluate the effectiveness of these pedagogical approaches. The study aimed to understand how these strategies lead to the development of essential professional skills among STEM graduate students by examining the incorporation of active learning and inductive teaching within the GAPS program. The findings reveal the impacts of innovative teaching practices on professional skills development in graduate education. They show that the GAPS program participants are highly satisfied with the course's practical skill adoption and knowledge integration. Furthermore, the increased class engagement offered an inclusive learning environment. This experience helped the participants to enhance their professional skills, especially in communication, teamwork, and project management. The results help inform best practices for integrating professional skills training into graduate curricula and enhance the preparedness of students for both academic and non-academic career paths.

Introduction

The 2017 Council of Graduate Schools report [1] highlights that most graduate programs lack sufficient training in skills that are highly required in professional fields. Research urges universities to combine internal consultation, external stakeholder feedback, and research to identify critical competency areas for graduate skills development [2]; as a result, many institutions have launched graduate professional skills training programs. However, developing impactful and effective programs remains a challenge primarily due to a lack of institutional resources and challenges securing faculty buy-in.

While active learning is widely used in technical training, its application in graduate professional skills development remains limited. This study sought to evaluate the effectiveness of the 2024 GAPS program in developing STEM graduate students' professional skills through the application of active learning and inductive teaching methods. Through the GAPS program, STEM graduate students participate in community-based experiential learning, applying key concepts to their thesis research with their cohort peers and building critical skills such as project management (PM), communication, and teamwork. This contemporary learning approach exposes students to key competencies relevant to their thesis. It further equips them with critical

skills, including problem-solving, leadership, adaptability, and analytical thinking. These skills are essential for academic as well as non-academic careers.

The Boyer 2030 Commission report for the year 2022 [3] highlights how strong education systems nurture the skills, knowledge, and behavior deemed valuable by employers. These essential skills include effective communication, critical thinking, teamwork, and their practical application in the real world. However, motivating graduate students to improve these skills remains a challenge. There is a clear lack of professional skill training in STEM graduate programs, which leads to the belief that these abilities should only be sought after finishing thesis research [4] [5].

This misconception complicates further attempts to have students enrolled in professional growth programs. For students without prior work experience or exposure to these skills, the value of such training may not be immediately clear. Unless students clearly understand its essence or how the training will be of benefit, they remain reluctant to participate or lose interest if they apply these concepts to their daily research activities. On the other hand, mandatory training can be viewed as a distraction, especially if it is not consistent with students' career interests [5] or personal goals. These factors demonstrate the significance of dealing with student perceptions and developing professional skills programs that match their academic and research goals.

Additionally, graduate students have diverse career development needs, which can either be discipline-specific or personal. Research suggests that communication and critical thinking skills are context-dependent rather than universal [6]. A one-size-fits-all approach toward professional development risks overlooking a student's strengths and specific needs. Furthermore, the appreciated conventional teacher-student mentorship paradigm is under threat from the shifting academic landscape, which is currently marked by shifting institutional goals [7], therefore creating a barrier.

In addition, today's faculty face increasing demands and may struggle to meet the diverse career aspirations of graduate students. For this reason, there is a need for a reevaluation of how professional development opportunities are designed to meet students' needs in teaching, research, and leadership. These are some of the factors that require consideration when designing a program.

The National Academies of Sciences, Engineering, and Medicine [1] recommends implementing a student-centered approach in STEM education, centering on developing skills that are key to career readiness. In this approach, the main focus is given to inquiry-based and active learning methods given that they are important in helping students to reach their potential. These approaches engage students through social interaction, collaborative activities, and reflective practice [8]. When students actively participate in the learning process, they gain greater autonomy over their learning. Although these methods appear promising, it is important that they deal with the existing challenges while considering resource constraints, including limited faculty availability at many institutions.

The NSF-funded Graduates Advancing Professional Skills (GAPS) program provides a unique, innovative, scalable solution to these challenges by incorporating professional skills

development into the student thesis research [9]. It employs active learning and inductive teaching while engaging students in a more community-based experiential learning environment. Although such pedagogical methods have been implemented in traditional coursework initiated by the Worcester Polytechnic Institute program in the 1970s [10] [11], their application in graduate professional skills development has not been studied empirically. This approach fulfills immediate academic needs and develops competencies, including problem-solving, leadership, adaptability, and critical thinking skills that are important for academic as well as industry success.

GAPS incorporates active learning and inductive teaching through various activities, encouraging students to apply project management skills directly to their research projects. For instance, through in-class discussions, an opportunity for a collaborative learning environment is developed where students discuss challenges and solutions. Further, online discussions and peer feedback support this shared learning experience.

Aligning with the Boyer Commission Report [3] goals, the GAPS program indeed seeks to effectively create a productive graduate student community, preparing students for academic and nonacademic careers. This study aimed to evaluate the effectiveness of the pedagogical approaches employed in the GAPS program, examining how they deliver content and strengthen students' critical skills in PM. The findings give insights into the effect of innovative teaching approaches on professional skills development in graduate education.

GAPS Program Approach and Design

The GAPS program is structured as a one-credit course. The key components include a project charter, which students develop through the semester, reflective writing, online discussion boards, and a final project presentation. The weekly 50-minute course design is centered around active learning and inductive teaching. Active learning engages students through meaningful activities like group discussions, problem-solving, and hands-on tasks instead of focusing on the traditional lecturing by instructors and note-taking by students [12]. Inductive teaching, on the other hand, presents students with an initial challenge and guides them through the principles required to solve the challenge [13].

This learning process fosters critical thinking as students engage to address problems presented. Both teaching methods have been proven to enhance learning while encouraging students to adopt a deeper interaction with their course materials [1] [13]. Additionally, this approach promotes active learning by engaging students in the construction of knowledge. These techniques are used in the GAPS program in several ways. Active learning is primarily incorporated through in-class discussion and the use of questions asked to students after 10-15 minutes of lecturing. These questions serve multiple purposes, such as seeking clarity, promoting debates on case studies, or encouraging sharing personal experiences.

In the case of inductive teaching, students are required to use their thesis as real-world examples. Students must develop a project charter throughout the semester, equipping them with hands-on experience with their projects. This immersive learning approach allows students to build knowledge from their experiences and use classroom concepts directly in their thesis. The

program encourages active engagement due to the students' invested interests, with the thesis project being the center of student learning. It also promotes a deeper and longer-lasting subject knowledge with retention.

A reflective writing assignment was used to support student learning outside class. By linking the learned concepts to their research or respective fields, students are encouraged to personalize their reflections. The basis of this approach is the learning theory of constructivism, which suggests that individuals assign meaning to new information by linking it to existing knowledge and reflecting on it [14]. Through reflection, students critically engage with course materials and apply the concepts in their thesis projects. The same concepts can be applied to solve industry challenges. This learning process follows a cyclical pattern involving personal experiences, reflective learning, and experimentation. Students adopting their thesis projects as case studies allows them to transform their research into a platform for acquiring and mastering professional skills. This change from passively absorbing information to actively practicing reflection promotes long-term retention[3] [15].

The online discussion boards, disseminated and managed on Canvas's learning management system, are incorporated to support peer learning and collaboration. The online class discussion forums run throughout the week, where students engage and share challenges, insights, and findings pertaining to their projects. This interactive platform allows students to ask questions, share ideas, and contribute to group problem-solving tasks. These peer interactions support the social learning process, where the students learn from their peers and broaden their understanding beyond individual capabilities [16]. At the conclusion of the course, in addition to submitting their final project charters, students are given a final team assignment: to showcase a project management (PM) topic of their choice and demonstrate how it applies to their thesis research in a group presentation format. A list of topics, with the relevant in-class discussions and after-class assignments, is shown in **Table 1.**

Additionally, the program features a badge recognition system designed to motivate students to engage with and master skills relevant to their area of specialization. Awarding students for achieving given milestones allows the badge system to encourage a sense of accomplishment and promotes participation in challenging tasks [17]. Further, we extended the 50-minute course session by offering a 20-minute open network session where students could stay behind after class and collaborate on their projects. Each student spent approximately one hour per week on their homework assignments outside the classroom. These interactive activities offer students greater opportunities to collaborate and nurture a sense of community and belonging.

Table 1. List of topics and corresponding in-class discussions and activities, with assignment.

Topic	**In-class discussions & activities**	**Assignment**
Project Charter	• Identify the elements of project charter that are relevant to your thesis research • Write down the key milestones and deliverables for your thesis	• Choose one project, can be thesis, and start your own project charter • Write down a clear goal with objectives • Start to map out all elements, including a contingency plan

	• Join group discussion, share your plan with your classmates	
The Work Breakdown Structure (WBS)	• Build a quick deliverable-based WBS for one of your research projects • Show and explain to others in the breakout room of your WBS and then share with class	• Integrate WBS for your project (two types) • Discuss the difference between phase-based and deliverable based WBS
Communication strategies	• Identify your stakeholders from the following list: advisors, classmates, department chairs, facility managers • Review case studies and discuss strategies for communicating with your advisor	• Develop your own communication strategy • Discussion board: How to make sure you understand your advisor's message? What if your experiments failed?
Critical path	• Discuss why critical path is important, share your personal stories	• Map your own critical path for your thesis
Lean concept	• Discuss how lean concept helped Toyota to become more effective • How can we leverage lean concept to improve our thesis research	• Reflect on how Lean concept is related to your thesis research • List a few things you would like to apply Lean concept
Time management	• What is your biggest challenge in time management • What does it mean in Chinese saying, "Haste makes waste"	• Identity inefficiency in your time management • Discuss strategies to avoid procrastination

Theoretical Framework

The study was grounded in a constructivist framework, which argues that knowledge is formed through active engagement with the environment. In this line of thinking advanced by Bruner [18] and Piaget [19], students learn more effectively when they actively build on prior knowledge by reshaping their understanding through interaction and reflection. Thus, learning is an interactive process. GAPS class activities incorporate an interactive approach utilizing active learning and inductive teaching pedagogies to help improve students' critical thinking, collaboration, and problem-solving skills. These learning approaches have long been considered effective in making learning more engaging and thought-provoking for students. Active learning focuses on students' class engagement, like in-class discussions and hands-on tasks, illustrating that knowledge is gained through experience instead of passive absorption [12] [13]. In contrast, inductive learning starts with students being given a problem scenario before being guided towards broader concepts. These cognitive theories, where real-world context-based information is used, help students construct their own meaning and enhance student retention and understanding of the material [21]. In this constructivist approach, teachers act as facilitators, creating an environment that challenges

students' preconceptions as they interact closely with the content and apply their knowledge to real-world situations.

Methodology

The analysis we present in this study is part of a broader NSF-funded research project exploring the impact of the GAPS course. Our previous efforts, based on surveys conducted before and immediately after the course, centered on evaluating students' interest and knowledge of project management skills, as well as their perceptions of the skills' value and applicability after graduation.

Across the study, participants generally perceived the course as beneficial for developing their PM skills. The current sample ($n = 19$) consists of students who enrolled in the GAPS PM course during the 2024 academic year. Participants represented a range of STEM disciplines, with 83% from engineering and 17% from other science-related fields, including food science and human nutrition, as well as human-computer interaction.

A mixed-methods approach, integrating surveys and focus group discussions, was adopted to provide a comprehensive view of participants' experiences in the program. The quantitative data was used in measuring student engagement levels and providing insights into the effectiveness of the pedagogies in PM. The surveys were employed to establish the relationship between participation in active learning activities and skill development. Additionally, the quantitative assessment helped track development in relevant professional skills including PM and teamwork, that are directly linked to the inductive teaching methods applied.

We applied a pre-course and a post-course survey design. The pre-course survey was done at the beginning of the semester. The same was designed to understand participants' motivations for enrolling in the program, their proficiency in specific skills and what skills they hoped to develop through the program. Questions in the survey included Likert-scale and open-ended questions to gather both quantitative and qualitative insights. The post-course survey, on the other hand, was conducted at the end of the semester. The same was used to evaluate participants' perceptions of the course's effectiveness, their satisfaction with the course format, and their self-assessed proficiency in the skills covered. The Likert scale included in the survey was used to measure skill levels and open-ended questions to gather additional feedback.

Two focus group discussions were carried out after each cohort semester's conclusion. These discussion sessions were designed to collect in-depth qualitative data about participants' experiences with the program. With the guidance of a semi-structured interview protocol, the discussion assessed themes, including 1) Clarity of instruction material, 2) Integration of knowledge, 3) The acquisition of new skills, 4) The relevance of content to participants' thesis work, and 4) Their overall program satisfaction. The focus group discussion allowed the participants to reflect collaboratively on their learning experiences while building on each other's experiences. This was also an opportunity to share challenges and propose areas for improvement. With participants' consent, the discussions were audio-recorded and transcribed for further analysis.

Data Analysis and Results

Data was analyzed using quantitative and qualitative approaches. The quantitative analysis adopted simple descriptive statistics to analyze the survey responses**.** The results were then tabulated to present a clear summary of participants' perceptions and self-assessed skill proficiency. The focus group data was analyzed using a thematic approach. First, the recorded sessions were transcribed and reviewed several times to gain a deeper understanding of participants' perspectives. Key statements were highlighted, initial codes were generated, and these were subsequently grouped into broader categories based on recurring patterns.

Themes were derived by clustering related codes, ensuring the themes accurately represented the data. The themes were also reviewed for relevance and coherence, where the overlapping themes were merged and the redundant ones discarded. Finally, the themes were interpreted while aligning with the study objectives to give insights into the program's effectiveness and areas for improvement. The analysis attempted to connect participants' qualitative feedback to the program's pedagogical strategies and theoretical underpinnings, providing a deeper understanding of its impact.

Table 2 shows an overview of students' self-assessed proficiency levels across various skills before participating in the GAPS course. The responses are categorized into three levels: Low, Moderate, and High.

Table 2: Proficiency Levels in Various Skills Before GAPS

Skill	Low	Moderate	High
Working in Diverse Groups	6[#]	9	4
Creative/Critical Thinking Skills	4	10	5
Research Skills	5	9	5
Writing Skills	2	10	7
PM Skills	6	9	4
Problem Solving Skills	5	9	5
Teamwork Skills	4	10	5

#: Number of students per response category.

Table 3 shows an overview of students' self-assessed proficiency levels across various skills after participating in the GAPS course. The responses are categorized into three levels: Low, Moderate, and High.

Table 3: Proficiency Levels in Various Skills After GAPS

Skill	Low	Moderate	High
Working in Diverse Groups	0	11	7
Creative/Critical Thinking Skills	2	10	6
Research Skills	0	10	8
Writing Skills	1	13	4
PM Skills	1	11	6

Problem Solving Skills	0	14	6
Teamwork Skills	0	7	11

The sample size of the post-course survey was ($n = 18$), as one student dropped out of the course due to scheduling conflicts. We also do not have demographics available, recognizing this as one limitation of our study. The results exhibited that the GAPS program substantially improved students' self-assessed proficiency levels across various skills, as evidenced by the comparison of Tables 2 and 3. Before the course, many students were not confident in their skills and self-rated low, particularly in working in diverse groups and PM skills, with six students indicating low proficiency in both. After participating in the GAPS course, there was a significant skill improvement, with no students rating their proficiency as low in working in diverse groups, teamwork, research skills, or problem-solving skills. These findings highlight the collaborative and critical thinking skills acquired through the program.

The shift from low to high proficiency levels in skills, including teamwork and problem-solving, demonstrates the success of the program in creating an engaging learning environment. Active learning strategies, like group discussions and hands-on tasks, encouraged students to apply their knowledge in real-world scenarios. Inductive teaching subsequently helped students develop essential skills through the project charter that encouraged collaborative problem-solving techniques. The survey data indicates a strong correlation between active learning and positive outcomes in students' thesis research. The data collected from the study further supports the effectiveness of inductive teaching, as students expressed increased confidence in applying learned concepts to real-world concepts like their thesis projects. Overall, the GAPS program enhanced students' self-assessment skills and equipped them with the necessary tools to thrive in both academic and professional settings.

Interpretation of Focus Group Discussion

The focus group discussion offered a dataset of qualitative insights into the student experiences within the GAPS program. Adopting thematic analysis, several key themes were identified, providing a comprehensive understanding of the program's strengths and aspects needing improvement, as shown in **Table 4.**

Table 4: Focus Group Discussion Results

Themes	Key Quotes	Interpretation
Enhanced Engagement in Collaborative Learning	"Rather than being a typical lecture , discussions made the content more engaging and practical by providing real -life scenarios for implementation "The professor was very engaging but probably what helped us most was the way we discussed the topics with our groups mates." "The discussion-based format lectures and the variety of guest speakers expanded the course by bringing diverse experience into the classroom."	Emphasis on accessibility and collaboration supports a supportive learning environment.

Supportive and Inclusive Learning Environment	"Discussions helped us learn from varied perspectives, provided clarity on implementing techniques and offered opportunities to collaborate across departments." "Collaborative learning environment. Helped me understand the material better." "This class allowed sharing of experiences of graduate life. I thought I was the only one going through struggles, but found others were facing similar challenges, and we learned to overcome the academic challenges together."	Applied open learning and peer mentorship valued by participants
Integration of Knowledge	"Reflective and creative writing assignments helped me remember the content taught each week and integrate different perspectives." "The final presentation enabled students to consolidate and apply what they learned throughout the semester."	Expanded student's world view through critical thinking
Practical Skill Application and Development	"After taking this course, I've come to realize that there are a lot of different tools and techniques that were taught in this course that I was not aware of, and how they would improve my quality of life, especially in research and work." "He explained how to talk to a processor, how to approach someone, how to build networking. So these are some life skills not only connected to professional life, which is something we need." "Improved my PM and teamwork skills.	Skill development and confidence gains affirm program's educational success.

The focus group findings from the GAPS program highlight the positive impact of active learning and inductive teaching approaches on student professional skills development. The course provided opportunities for high student engagement and collaboration through group projects. Participants emphasized that the discussion-based format replaced traditional lectures, making the content more engaging and practical by offering real-life scenarios. This method fostered a supportive learning environment and encouraged students to learn from diverse perspectives, enhancing their understanding and application of course material.

Further, the priority given to collaborative learning and peer mentorship encouraged the students to cultivate supportive and inclusive learning environments. The students could engage with each other and find various solutions to their tasks through discussion boards and after-class meetings. This activity prompted students to share their experiences in a safe space and deal with academic problems together. Moreover, these findings highlight the significance of community in the learning process. The reflections, creative writing assignments, and final presentations, helped with critical thinking and integration of knowledge.

The students were able to build on the knowledge shared in class and connect it to their personal experiences and how they understood it in class. This process supported students to consolidate their learning effectively. In general, the program's active learning and inductive teaching

approach successfully equipped students with new knowledge and skills. This boosted students' confidence levels and enhanced their PM and teamwork skills. These skills are essential not only for academic success but also for professional growth.

Based on focus group discussions, the strengths of the GAPS program were highlighted, especially in encouraging the development of soft skills like teamwork, which they adopted effectively in their teams and personal projects. These discussions, however, also revealed that there are some areas that require more attention, such as clearer teaching structures and more practical examples. The positive feedback regarding the collaborative learning environment and supportive resources underscores the influential role of learning communities in shaping program outcomes, highlighting the importance of their continued development and retention.

Discussions

The findings of the GAPS program align with the theoretical framework that guided its design. The basis of such a framework is the assumption that knowledge is developed through active engagement with the environment. Students can build effectively on their prior knowledge, according to the theories of Bruner [18] and Piaget [19], through interaction and reflection. Integrating active learning and inductive teaching methods under the GAPS program promoted critical thinking, teamwork, and problem-solving, improving student outcomes.

For instance, in a lecture centered on communication skills, students were given three case studies for in-class discussion before introducing key communication principles. The scenarios included scheduling meetings with advisors, reporting slow progress or negative lab results, and seeking approval for summer leave to pursue internships. The discussions were often highly engaging, with students eager to explore potential solutions and seek guidance from the instructor, given the relevance of these topics to the student's daily experiences in graduate school. Following these discussions, the instructor introduced foundational communication principles and facilitated a guided exploration of suitable strategies and responses for each scenario.

This approach is an example of how active learning and inductive teaching methods can be used to make learning effective for students. Active learning focuses on students' participation in various learning activities, discussions, problem-solving solving and hands-on tasks in class and practical assignments, illustrating that knowledge is experienced as opposed to passively acquired [12] [13]. In contrast, inductive learning starts with given examples, problems, or scenarios to work towards a broader concept. This method fits in well with cognitive theories [20] which suggest that real-world, context-based information, enhances both the retention and understanding of material. In this constructivist approach, teachers act as facilitators, nurturing an environment that encourages students to question their assumptions, interact deeply with the material, and apply their knowledge to real-world contexts.

In aligning their course content with thesis projects, the students were able to develop and retain professional skills that are applicable to both academic and industry needs. It was revealed from the findings that students had improved their communication with faculty advisors. Additionally, students were now more organized in the management of their theses. Furthermore, students said

that they were provided with essential resources to aid them in their professional pursuits, supporting studies that active learning boosts student performance in science fields [21]. A similar trend was qualitatively confirmed in the GAPS program. Active learning improved student performance in gaining professional skills. The participants in the GAPS program observed significant development in their PM skills, especially in time management, task prioritization, and resource allocation, which were considered valuable for both academic and professional growth. Participants also valued the opportunity to work in diverse groups, which facilitated the enhancement of interpersonal skills and problem-solving skills through exposure to a variety of perspectives. Although the inductive teaching approach was praised for prioritizing active learning, some students felt that more clarity and guidance would be helpful, especially for those unfamiliar with the method. While the course content was generally well-regarded, the pacing proved challenging. Lastly, the interactive tools, especially the dashboard and planner, were positively received for their effectiveness in tracking progress and enhancing organizational skills.

Drawing from the survey results, the program's success is demonstrated. All participants agreed that the course content was useful. The high level of agreement (90%) regarding the course's effectiveness further endorses the idea that active learning, as demonstrated in class discussions and problem-solving activities, encourages deeper engagement with the class material. Qualitative insights from the focus group discussion further supported the program's consistency with constructivist principles. Acknowledging that the program design enhanced their confidence in applying PM skills to real-world contexts, students praised the program's interactive and collaborative nature, which supports Piaget's assertion that active engagement and problem-solving in authentic scenarios lead to stronger cognitive development [19].

The foundation of peer networks and inspiration to pursue new academic or professional interests was an unanticipated outcome. This outcome emphasizes the broader benefits of a constructivist approach. Through encouraging social collaboration and reflective practice, the GAPS program enabled the students to gain professional skills and nurtured a strong and supportive learning community that students used to strengthen their connection to the course material and align it with their academic objectives.

Implications for Practice

The findings from the study highlight the benefits of integrating active learning and inductive teaching into graduate STEM education. These pedagogies emphasize practical, real-world applications and critical thinking. The learning approaches used in the GAPS program have been applied to enhance students' transferable skills like PM, teamwork, and communication, which are necessary both in the academic and industrial settings. This study illustrates how intentional research-based pedagogical practices can support the acquisition of graduate skills [3] [6]. Through GAPS, students were able to improve teamwork, problem-solving, and research skills. The GAPS project-based approach effectively closes the gap between academic training and professional skill development by aligning course content with thesis work. Other institutions can consider implementing these strategies in their STEM graduate programs to improve students' long-term retention and adaptability.

This study suggests that tailored professional development programs can help students acquire essential professional competencies in graduate education. Although management skills such as leadership and collaboration are often overlooked in traditional curricula [1] [2], these skills are essential as they help students transition successfully to the job market. To address this gap, universities can offer flexible, resource-rich programs that balance academic rigor with practical support. Peer collaboration can be incorporated into the learning outcomes to address challenges related to the lack of faculty and resources.

Additionally, students in the GAPS program valued the class collaboration as it offered them an opportunity to see what others were doing and, in turn, improve on their projects. These approaches to learning allow the students to take the lead in their learning process. Construction of these theories, Bruner's (1966) and Piaget's (1970) [18] [19] point out that students are active participants in shaping their learning experience, which results in knowledge retention and application.

Lastly, the GAPS program demonstrates that professional skills training can have broader career implications. GAPS inspires students to explore new academic and professional interests while building strong peer and external stakeholder networks. This concept provides support for career development through stakeholder involvement [22]. Students are given opportunities to connect with professionals from the field. The program's practical and simple design offers a replicable model for other institutions. By addressing challenges and expanding on its strengths, universities can ensure graduate education prepares students for both academic excellence and career advancement.

Acknowledgements

This work is supported by the National Science Foundation under Grant No.1954946. Any opinions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation. We acknowledge help from Emmanuel Owusu-Sekyere and Andrew Guhin for their assistance in the coursework and collecting data for the focus study group. We also thank Kathy Jackson for her assistance in evaluating the program and offering valuable suggestions.

References

[1] National Academies of Sciences, Engineering, and Medicine, "How people learn II: Learners, contexts, and cultures," 2018. [Online]. Available: http://nap.nationalacademies.org/24783. [Accessed 6 jan 2025].

[2] D. Denecke, K. Feaster and K. Stone, "Professional Development: Shaping Effective Programs for STEM Graduate Students," Washington, DC, Counc Grad Sch, 2017.

[3] Boyer 2030 Commission, "The equity/excellence imperative: A 2030 blueprint for undergraduate education at US research universities.," Association for Undergraduate Education at Research Universties (UERU), 2022.

[4] C. M. Golde and T. M. Dore, "At cross purposes: What the experiences of today's doctoral students reveal about doctoral education," Eric, 2001.

[5] G. E. Walker, C. M. Golde, L. Jones, C. A. Bueschel and P. Hutchings, "The Formation of Scholars: Rethinking Doctoral Education for the Twenty-First Century," Jossey-Bass, San Francisco, CA, 2008.

[6] T. M. Hora, "Career-readiness initiatives are missing the mark," Inside Higher Ed,, 2023. [Online]. Available: https://www.insidehighered.com/views/2023/01/11/career-readiness-initiatives-are-missing-mark-opinion.

[7] Y. Hardaway, M. Ponce and M. Crowe, "Supporting the unique career development needs of graduate students," *NACE Journal,* 2023.

[8] O. Sengul, "Effective Learner-Centered Approach for Teaching an Introductory Digital Systems Course," *Journal of College Science Teaching,* vol. 52, no. 2, pp. 88-94, 2022.

[9] A. Gansemer-Topf, S. Jiang, Y. Liang and D. Chen, "Evaluating the implementation of project management skills training within STEM graduate education," in *ASEE Annual Conference & Exposition*, Baltimore, 2023.

[10] Worcester Polytechnic Institute, "Creating the WPI Plan: Pioneering and perfecting," n.d. [Online]. Available: https://www.wpi.edu/about/wpi-history/wpi-plan. [Accessed 6 january 2025].

[11] L. Breslow, "Wrestling with Pedagogical Change: The TEAL Initiative at MIT. Change: The Magazine of Higher Learning," *The Magazine of Higher Learning,* vol. 45, no. 5, pp. 23-29, 2010.

[12] M. Prince and R. Felder, "Inductive teaching and learning methods: Definitions, comparisons, and research bases," *J. Eng. Educ,* vol. 95, no. 2, p. 123–138, 2006.

[13] M. Prince and R. Felder, "The many faces of inductive teaching and learning.," *Journal of College Science Teaching,* vol. 36, no. 5, pp. 14-20, 2007.

[14] K. H. D. Tang, "Student -centered approach in teaching and learning: What does it really mean?," Acta Pedagogia Asiana 2(2):72-83, March 2023. [Online]. Available: https://www.researchgate.net/publication/369563068_Student-centered_Approach_in_Teaching_and_Learning_What_Does_It_Really_Mean. [Accessed 4 Oct 2024].

[15] C. K. Y. Chan and K. K. W. Lee, "Reflective literacy: A multilevel pespective on the challenges of using reflections in higher education through a comprehensive literatire review.," *Educational research Review,* vol. 32, no. 100376, 2021.

[16] K. Scager, J. Boonstra, T. Vulperhost and F. Wiegant, "National Library of Medicine, National Center for Biotechnology Information," CBE Life Sci Educ., Winter 2016. [Online]. Available: 10.1187/cbe.16-07-0219. [Accessed 4 Oct 2024].

[17] J. Hamari, J. Koivisto and H. Sarsa, "Does gamification work?—A literature review of empirical studies on gamification," in *Proceedings of the 47th Hawaii International Conference on System Sciences, 2014*, 2014.

[18] J. S. Bruner, Toward a Theory of Instruction. Cambridge, MA: Harvard University Press., Cambridge, MA: Harvard University Press, 1966.

[19] J. Piaget, "Piaget's theory," in *Carmichael's manual of child psychology*, vol. 1, Wiley, 1970, p. 703–732..

[20] C. E. Hmelo-Silver, "Problem-based learning: What and how do students learn?"," *Educational Psychology Review,,* vol. 16, no. 3, p. 235–266, 2004.

[21] S. Freeman, S. L. Eddy, M. McDonough, M. K. Smith, N. Okoroafor, H. Jordt and M. P. Wenderoth, "Active learning increases student performance in science, engineering, and mathematics.," in *Proceedings of the National Academy of Sciences 111(23), 8410-8415*, USA, 2014 JUN 10.

[22] L. Berdahl, 2023. [Online]. Available: https://universityaffairs.ca/career-advice/five-best-practices-for-graduate-student-professional-development/. [Accessed 4 January 2025].