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Implementing Professional Skills Training in STEM: A Review of the Literature

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Abstract

Background: Project management and other professional skill training is often lacking in graduate student education, typically as a result of limited resources, lack of faculty buy-in, and narrow focus on thesis research. To address this need and with support from NSF, we are developing the Graduates for Advancing Professional Skills (GAPS) program at Iowa State University. To aid the initial development of this program, we conducted a literature review to understand the current context of the development and implementation of professional skills in higher education curricula, with specific interest in STEM fields.

Purpose: The purpose of our study was to identify best practices related to implementing professional development skills into an academic curriculum. The goal was to utilize this information in the development, planning, implementation, and assessment of our GAPS program.

Design: We engaged in a systematic literature review. We focused on the curricular and pedagogical approaches to implementing these skills, results of the initiatives, and methodologies used to assess their effectiveness.

Results: Our literature review uncovered the "messiness" of teaching and learning of skills such as project management. There is often not one approach or definition of project management – it may change based on scope of project and context. Successful implementation requires adaptability, mentorship, problem solving, creativity, and communication. Additionally, project management has been referred to as a "threshold concept" and requires a certain level of intuition that cannot necessarily be gained through traditional classroom education.

Conclusions: There appears to be an agreement on the importance of implementing project management skills at the postsecondary level. Our work illustrates the difficulty associated with undertaking this endeavor and provides guidance on approaches that can make these initiatives more beneficial. Although this literature was conducted to aid in the planning for our specific project, the synthesis of the extant works can inform other faculty and industry leaders who are interested in teaching and applying project management techniques in their courses or companies.

Keywords: project management, literature review, graduate education, engineering

Part I: Context of the Study

Students in graduate programs in STEM dedicate a significant amount of time and energy in learning the research process and applying these processes to individual or collaborative research initiatives. This myopic focus on research skills and the scientific process ignores other critical skills needed in their careers post-graduation (Leshner & Scherer, 2018; Wendler et al., 2010). A recent survey of engineering graduate students echoed what large companies such as GE, DuPont, and Boeing have believed: strong project management skills are needed for effective STEM leadership (Denecke, Feaster, & Stone, 2017). To address this need and with support from NSF (Grant # 1954946), we are developing the Graduates for Advancing Professional Skills (GAPS) program. In conceptualizing our project we began by defining professionals skills as areas of competence that go beyond knowing and applying academic

content but which are necessary to be successful in industry and the academy (Denecke et al., 2017). These skills can include a range of competencies such as communication, critical thinking, and teamwork. For this grant, we focused specifically on the skill of project management. The program is based on a communities of practice model that involves the forming a doctoral learning community and a course that infuses project management skills into students' thesis research projects.

We adopted a communities of practice (CoP) framework. CoPs are defined as "*Groups of people who share a concern, a set of problems, or a passion about a topic, and who deepen their knowledge and expertise in this area by interacting on an ongoing basis*." (Wenger, McDermott, & Snyder, 2002; p. 304) The basic premise behind CoPs is intuitive: we all learn in everyday life from the communities in which we find ourselves. Participation in CoPs results in the accumulation of newer or deeper levels of knowledge through the group activity and the development of expertise. Therefore, a CoP is an effective way to overcome many problems that are difficult to solve by traditional structures (Sánchez-Cardona et al., 2012; Smith et al., 2003). At many institutions, the development of learning communities has been one approach that mirrors the benefits of CoP. Research on learning communities has illustrated the importance of these programs for student retention and academic success (Antonio, 2004; Benjamin, 2015; Mayhew et al., 2016). Although focused primarily on undergraduate students, learning communities have also shown promise for enriching the graduate student experience (Kraska, 2008).

Several critical factors influencing the effectiveness and sustainability of CoPs have been identified, including motivation to share information and willingness to collaborate (Bates, 2016). Kimble & Hildreth (2008) provided a review of CoPs in education with practitioner experience. Buysse et al. (2003) examined the CoP model as a framework for integrating educational research and practice. Technology also provides a wide range of tools that can support CoPs (Wenger, 2011). The extensive research on CoPs provided a solid foundation on which to build the GAPS program. After identifying the approach we wanted to use to frame our work, we began examining literature related to teaching or integration of project management skills into the curriculum. This investigation serves as the purpose of this paper: to identify best practices related to implementing professional development skills into an academic curriculum. Subsequently, we would utilize this information in the development, planning, implementation, and assessment of our GAPS program.

Part II: Literature Review:

We identified literature using Google scholar, EBSCO host Education Full Text, and EBSCO host ERIC. We used the following keywords in our search: engineering education, graduate education, project management, professional skills, soft skills, lean manufacturing, lean six sigma, and project management methodology. We then reviewed each article specifically noting the population that was studied, methods, and primary results. The following sections outline some of our key findings from 10 articles most closely related to our topic. A summary of the articles are providing in Table 1.

Populations Studied

The articles reviewed examined project management and soft skills from a variety of perspectives. Articles that focused on students included undergraduates in information science majors (Smith & Smarkusky, 2008), chemical engineering undergraduates (Gilbuena et al., 2015), students in information systems and business (Poston & Richarson, 2011), and graduate students in engineering (Zwikael et al., 2014). Studies collected information from engineering faculty members (Zwikael et al., 2014; Taylor,2011), technical writing faculty members (Taylor, 2011), project managers (Joslin & Muller, 2016; Pace, 2019), and engineers in the workplace (Trevelyan, 2010). Another study (Shuman et al., 2005) examined programs that taught and implemented ABET's professional skills. The diversity of populations studied demonstrates that the topic of project management has been investigated through the lens of various stakeholders. Nevertheless, the lack of consistency among populations makes it difficult to assess the generalizability of results to similar populations or to determine if the results are based on the population studied, the context (i.e., institution versus industry), or the delivery of project management skills.

Methods

Engineering and STEM fields traditionally have relied on quantitative methods to address research questions. Surprisingly, over half of the studies we reviewed used more qualitative methods such as direct observation, analysis of reflective writings, presentations, and notebooks, document analysis of programs and curriculum, interviews, and recordings. Quantitative data from rubrics, surveys, and pre and post tests were also analyzed. The variety of research methods used to explore project management skills are important to consider as we evaluate and assess the GAPS program. Studies using quantitative designs were able to demonstrate differences before and after project management initiatives were implemented. These studies provided a relatively concise and clear evaluation of the effectiveness of project management skills.

The preponderance of qualitative methods may point to the difficulty in assessing outcomes related to project management. Project management skills often are viewed as soft skills that may be more difficult to assess than more technical skills such as computer programming or solving a mathematical problem. Cajander et al. (2011) described project management as a "threshold concept"; it is difficult to learn and simply practicing or imitating is not enough. Therefore, the complexity of measuring this learning must include richer evaluation measures beyond simple numbers. Given the difficulty in this assessment, qualitative research methods, which can capture nuances and explore "why" and "how," may be more appropriate for understanding how students are learning and applying project management skills.

The multiple approaches for designing a study and analyzing data are useful as we consider our development of formative and summative assessments. Each methodology has its strengths and limitations. Understanding how others have designed their research studies and the implications for these choices will assist us as we undertake our own research and assessment activities.

Results

Our review of the results captured a significant amount of information related to the development and assessment of project management. In this section we highlight those results most closely applicable to our project and which can inform other research related to this topic.

Shuman et al.'s (2005) work provides a significant number of examples of institutions who are trying to teach and assess ABET professional skills. We shouldn't have to recreate the wheel while also realizing that in the past 15 years, students skills may have changed and the tools used to assess these skills may have evolved.

Zwikael et al. (2014) used pre and post tests to assess student learning and knowledge related to project management after implementing a simulation based training (SBT). The research team compared post-test scores based on prior knowledge, attitude, and success in implementation and found differences between groups. Students who had high prior knowledge did not see improvements in knowledge after SBT but did see higher motivation for learning than those with low or medium level of prior knowledge. Students who began with prior knowledge were consistently higher (pre and post test) than their peers with less knowledge. Level of attitude did not influence declarative knowledge but significantly influences level of learning energy. Those with high attitudes toward SBT dramatically increased their attitude toward SBT after experiencing it and those with low attitudes of SBT decreased their attitudes over the semester. Lastly, students who failed in the SBT project management project had lower declarative knowledge but higher learning motivation prior to SBT. After SBT, both groups gained in knowledge at about the same rate. Students who succeeded had initially lower motivations for learning than those who failed but after the SBT success, they dramatically increased their energy motivation. Those who failed decreased in the learning energy.

Prior knowledge and attitude can dramatically influence learning and motivation. Students who failed in their project did make gains in knowledge; a finding consistent with the adage "we learn even in failure." Nevertheless, the failure also influenced motivation. The results of this study have significant implications for our work and for others who are interested in assessing the effectiveness of a new skill or program. Assessing student learning must also consider a student's prior experience, attitudes toward the task and also their performance with the task.

The GAPS program is designed to provide students with useful feedback on their progress and projects. Taylor (2011) and Gilbuena et al.'s (2015) studies examined the role of feedback and its influence on student performance. Taylor found that when receiving feedback on their writing, students preferred more direct and critical feedback. Gilbuena et al.'s study focused on providing coaching and feedback to students related to capstone projects. They found that affirmative feedback had the most positive impact on students' ability to develop professional skills. The authors concluded that the affirmative feedback helped students feel as though they were a legitimate member of the community, which subsequently, also influenced their skill development.

Several studies provided insights into the teaching and learning aspects of project management. Joslin & Muller (2015) examined the relationship between project governance and success. They defined project governance as "the use of systems, structures, or authority, and processes to allocate resources and coordinate or control activity in a project" (Joslin & Muller, 2015). They found that project managers were more successful when they focused on stakeholder concerns and when they focused on controlling the outcome of a project rather than the behaviors of individuals. Their study stressed the importance of teaching project governance concepts within project management.

Cajander et al. (2011) concluded that radical changes in a project (i.e., when a faculty member changed course direction or a customer changes direction) actually resulted in higher level learning assuming students were able to work through the messiness. This finding provides some comfort as we embark on this new project. New courses, grant work, and research rarely go as anticipated and will require changes. Navigating these changes as a research team and assisting student navigate these changes will be critical for student learning.

Part III: Conclusion

The research we reviewed included a variety of populations, methods, and results. Despite these differences, we noticed two reoccurring themes: a) project management skills are critical skills, especially for students interested in engineering, and b) project management skills are difficult to teach and difficult to assess. These two themes have significant implications for the development of the GAPS program. We can work with the knowledge that our purpose of developing project management skills is critical. We also will face significant challenges of how to teach these skills and assess whether students have learned these skills. We are continuing to review the literature and plan to do a more comprehensive scan of articles published in engineering journals that may lend insight into the development of our project. Thus far the literature has provided a compass as we use our own project management skills to develop and implement the GAPS learning community and also will continue to inform our assessment and evaluation of the project.

Table 1

Authors	Context	Population	Sample Size	Methods	Key Findings
Smith, Smarkusky	Assessing team competency and project management skills in students over the course of their degree program. Competency matrices used to assess development	Undergraduate students majoring in Information Science	N/A	-Team competency matrix -Project knowledge matrix -Examples of student team projects	General teamwork and communication skills must be formed before project management. Competency matrices are an effective way of assessing student progress in professional skills.
Poston, Richardson	Development of two University courses for multiple majors. Courses designed for team projects. Project Management Institute (PMI) representatives brought in as team mentors.	Undergraduate students (Information Science, Business, and others). Local PMI chapter members.	All students enrolled in the courses during first 5 years	-Student surveys -Project management contest judged by industry and business leaders -Feedback and progress panels	PMI mentors had challenges with inconsistent approaches. Feedback sessions involving students and mentors aided in improving the program and keeping track of groups' progress.
Gilbuena, Sherrett, Gummer, Champagne, Koretsky	Assessing how engineering students gain professional skills during capstone project. Student teams were assigned a coach.	Senior undergraduate chemical engineering students selected from two cohorts of 80 students.	12 students split into 4 teams	-Recordings of coaching sessions -Student deliverables (e.g. notebooks) -Student surveys	Affirmative feedback had most positive impact on students' ability to develop professional skills.
Pace	Many project management methodologies exist (traditional waterfall, lean, agile, etc.).	Project managers in various industries with at least 5 years	367 usable responses	-Analyzed data from previous survey of North American project managers. Survey	Project management methodology had weak to moderate correlation with success.

	Investigating success of different methodologies.	of experience, age 25 or older, and experience with multiple project management methodologies.		not conducted by the author.	Project manager experience does not guarantee success. Every project is unique, so no one methodology will work unilaterally.
Cajander, Daniels, McDermott, von Konsky	Professional skills are difficult to assess with traditional means. Testing if reflective writing can serve as a better assessment and skill-building tool. Key goal is to help students use skills intuitively, not just mimic the language and behaviors.	Undergraduate students and university professors.	All students in two-semester course unit.	-Student written reflections -Used Bloom's scale, Hatton and Smith framework to analyze	Major shift in the project caused students to obtain higher professional skill level. Reflective writing was necessary for both students and professors. Professional skills are a threshold concept.
Zwikael, Shtub, Chih	Simulation-based training (SBT) was tested as a means of individualizing project management education. SBT can adjust for different challenge levels. Most challenging levels force users to weight probabilities and make project planning changes accordingly.	First study conducted with engineering faculty members with experience in project management. Second study conducted with graduate students with variant experience.	14 faculty members, 55 graduate students	-Project Team Builder software used for SBT -Pre and post SBT surveys	Students with high prior knowledge showed large jump in learning energy but didn't improve in declarative knowledge. Students with low prior knowledge improved in declarative knowledge after SBT. Students with high prior attitude towards simulation increased in learning energy but students with low prior

					attitude decreased in learning energy. Attitude towards simulation and performance in the simulation did not make large changes in declarative knowledge.

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