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Preparing Undergraduates for Project Management on the Manufacturing Shop Floor

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ABSTRACT

The purpose of this paper is to establish a project management pedagogy for applied engineering students focused on a manufacturing career. To accomplish this, semi-structured interviews were conducted with 15 manufacturing engineering managers from a variety of manufacturing companies, in conjunction with the development of custom project management training for their support staff. From the interviews and questions, a set of core project management competencies for applied engineering students was developed. A review of the Project Management Institute's body of knowledge and the engineering management body of knowledge was undertaken to validate and establish relevancy for the defined competencies.

A review of literature revealed a paucity of pedagogical articles addressing project management education targeted at manufacturing shop-floor operations. A comprehensive undergraduate pedagogical approach utilizing active learning modules is presented for instructors to teach the currently demanded project management core competencies needed for a manufacturing environment. Graduates will be able to speak to project situations relevant and meaningful to production when interviewing for entry level positions with engineering managers. The Kolb Learning Cycle is used as a foundational education theory for active learning. The structure and methodology include technical objectives and development of soft skills required for effective project management. The approach considers project management capability maturity models from the International Institute for Learning. Its model is adapted to analyze core competencies presented by the pedagogy and is directed at the shop-floor level for manufacturing operations.

Introduction

A great deal of news media and trade journals point to a significant amount of re-shoring of manufacturing operations, reversing the off-shoring trends started in the 1980s (Northam, 2014). In a 2013 survey of over 275 chief executives, Grant Thornton LLP found that companies were either "likely" or "very likely" to bring back previously off-shored work to the United States including IT services (42%), components/products (37%), and materials (34%) (Bond, 2013). This revitalization of US manufacturing will be managed by many companies that have gone "lean" during the interim, and these manufacturing organizations will rely on project teams to replace a flattened middle management (Brown & Hyer, 2010). A review of literature and fieldwork while conducting industrial training for various manufacturing companies provided substantial evidence of this need. While engineering managers were well versed in project management requirements, their support staff did not have the level of capability needed to execute projects effectively. Three critical project categories that frequently occur at the shop-floor level include planned maintenance shut-downs, manufacturing process improvements, and capital acquisition/installation projects.

In teaching project management at the university level, faculty must consider that manufacturing engineering cultures typically fail to embrace formal PM practices. Many experienced project managers consider "the formal use of PM tools and procedures to be wasteful" of time and resources, and "all but the most rudimentary tools were far too cumbersome" (Kasten, 2014). Additional research on PM found that another possibility was that project management tools were sometimes not used well (Besner & Hobbs, 2006). Kasten (2014) summed up well, stating that there is a mismatch between what is being taught to undergraduates and what is being used in industry.

The challenge in teaching project management at the undergraduate level is that there is extremely diverse curriculum content and no uniform definition of an "ideal" project structure (PMI, 2013). The Project Management Institute's Body of Knowledge (PMBOK) and the Engineering Management Body of Knowledge (EMBOK) provide technical requirements expected from newly graduated technologists and engineers hired into manufacturing operations. Interpersonal (soft) skills are considered "behavioral competencies" by the Project Management Institute (PMI). At the shop-floor level, PMI specific competencies include communication, conflict resolution, influence, team building, and group facilitation. The instructional conundrum is thus twofold: 1) What are the correct technical skills required, and 2) How to integrate required soft skills.

Purpose

The objective of this research was to conduct an exploratory investigation into project management pedagogy for undergraduates pursing an applied engineering, rather than an engineering, baccalaureate degree. While the Association of Technology, Management, and Applied Engineering (ATMAE) defines project management as a core competency, specific higher education disciplines must define their own competencies, grounded in instructors' areas of expertise (Meier & Brown, 2008). The goals of this study were to define a set of core project management competencies and to define a course structure for project management education to support a manufacturing shop-floor environment. The intended course proposal would position graduates to meet the first year of employment expectations, while simultaneously providing education theory to take companies to the next level on the Capability Maturity Model - Integrated (CMMI) developed by the International Institute for Learning (IIL) (IIL, 2016) for project management.

The review of literature for this paper revealed a lack of research on short-range projects typical of production environments. Given that manufacturing is generally considered as a key economic base, this gap in project management pedagogy needed to be addressed. Specifically, this study sought to address the following research questions:

1. What are the core project management competencies sought by manufacturing engineering managers for their staff?
2. What is an appropriate pedagogical approach for undergraduate project management courses focused on these priorities?
3. What would be a recommended pedagogy for an applied engineering focused project management class?

Methodology

As part of a program to provide customized training classes from 2008-2014, one of the researchers conducted semi-structured interviews with engineering managers from 15 manufacturing companies. The semi-structured interview allows for flexibility to add additional exploratory questions to a set of pre-determined and pre-ordered questions. Using this approach, rather than a structured interview, allowed for in-depth discussion on topics relevant to each engineering manager. The training classes were provided for engineering professionals working with discrete manufactured products, including pharmaceuticals, consumer goods, and industrial products. Custom content was developed for individual companies using the interviews, PMBOK, and EMBOK as the backbone of the material presented. Subsequently, this fieldwork was augmented by a review of literature for project management core competencies and manufacturing-specific project management pedagogy.

In the following sections, PMBOK and EMBOK background is presented to establish the technical foundation for project management in the manufacturing environment. The CMMI is also discussed to establish the current state of project management maturity in the manufacturing industry. This established the need and developed the goal for student outcomes. Next, a review of literature and summary of the semi-structured interviews are presented to define core competencies that engineering managers seek from their staff and, by extension, from newly hired undergraduates. The core competencies are mapped to the PMBOK and EMBOK to demonstrate how the pedagogical areas correlate to technical project management skills. Finally, a pedagogy consisting of course objectives, course structure, and learning module details is provided.

Background

PMI defines project management as the application of knowledge, skills, tools and techniques to manage activities required to meet objectives within a project scope (PMI, 2013). The role of a project manager is to lead a team and to balance competing constraints of scope, cost (including budget and resources), and time (schedule and deadlines) (Gray & Larson, 2011). The balance of these constraints is impacted by the risks of the project and the desired quality of the outcomes. PMBOK, fifth edition, contains 47 project management processes grouped into 10 separate knowledge areas (PMI, 2013) providing best practices, techniques, and tools for managing projects. However, PMBOK is not intended to be a "how to" manual, nor can it define a uniform project management methodology since each organization and project may be considered unique. Also, a key PMI tenet is that the practices presented are simply a guide and do not need to be applied uniformly; organizations are responsible to implement a subset of processes and to establish the degree of required robustness. The EMBOK establishes competencies for engineering managers, practicing engineers, and educators (American Society of Mechanical Engineers, 2010). EMBOK requires that practitioners utilize "professional judgment, experience, and discretion" to determine practices appropriate to situations. EMBOK Domain 4 contains the generally recognized best practices and concepts for engineering projects.

Two capability maturity models are presented to characterize the current state of project management methods at the manufacturing shop-floor level. The original Capability Maturity Model is shown in Figure 1 (Paulk, Weber, Garcia-Miller, Chrissis, & Bush, 1993). Subsequently, Kerzner and the International Institute for Learning, Inc. crafted an interpretation specific to project management maturity, which is depicted as the CMMI in Figure 2 (IIL, 2016). The review of literature found three studies, conducted over a 12-year period, which assessed the maturity of project management within manufacturing environments. A 1997 paper by Ekmark et al. placed the project management maturity at Level 1. Project planning and execution were mainly ad hoc, and generally focused on immediate problems. Schedules and budgets were often exceeded and quality compromised to meet deadlines (Ekmark, Nelson, & Mårtensson, 1997). Approximately 10 years later, a 2006 survey revealed little movement for capabilities exhibited by manufacturing operations (Grant & Pennypacker, 2006).

FIGURE (1): CAPABILITY MATURITY MODEL (Paulk et al., 1993)

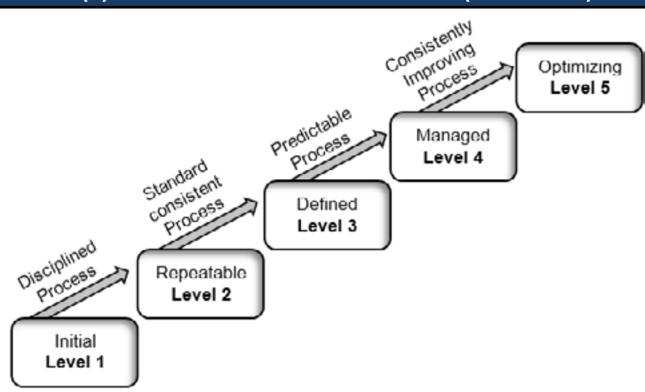
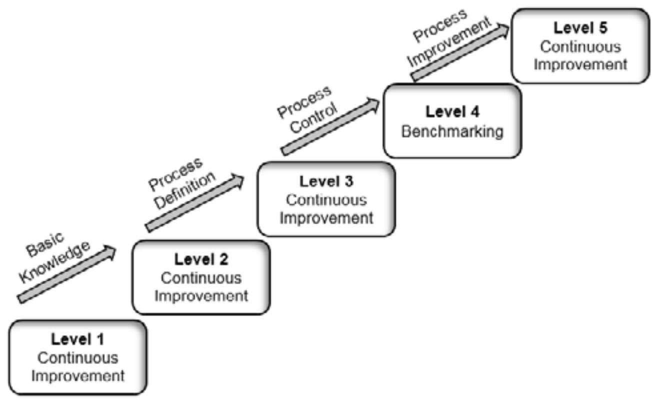


FIGURE (2): CMMI: FIVE LEVELS OF PM MATURITY (IIL, 2016)



The 2006 Grant and Pennypacker survey of 900 project management practitioners yielded 126 valid responses. Of the 126 responses, 15% (19 surveys) were from the manufacturing industry; no additional information was provided on type of manufacturing or company size. However, mitigating the low manufacturing industry response rate, and as one of the study's most important conclusions, the authors stated that project management maturity was very consistent across all industries studied (Grant & Pennypacker, 2006). The exception was the professional services industry, accounting for 21% of the responses, which tended to excel at schedule development, resource planning, and cost control. As 81% of the responses (102 surveys) showed no statistically significant differences, it was reasonable to accept the study findings as valid for the manufacturing industry. Table 1 breaks out the manufacturing operation data, showing the percentage of operations and the project management maturity achieved. It shows that a majority of operations fall at Level 1, with a decreasing percentage achieving further maturity. IIL considers advancement to Level 2 as having trained personnel develop company-specific processes for planning, scheduling, cost control, etc. As IIL also recommends a PMI-certified project management professional (PMP) on staff, the proposed pedagogy is mapped to PMBOK to introduce students to PMI and establish an educational background to pursue PMP certification once sufficient experience is achieved. The 2006 Pennypacker study was validated three years later by Yazici, further sanctioning validating use for this research (Yazici, 2009).

TABLE (1): CAPABILITY MATURITY LEVEL: PERCENTAGES FOR MANUFACTURING OPERATIONS

Knowledge Area	Level 1	Level 2	Level 3	Level 4	Level 5
Schedule Development	70.6	11.8	11.8	5.9	0
Resource Planning	70.6	23.5	5.9	0	0
Cost Control	58.8	17.6	23.5	0	0
Scope Change Control	41.2	41.2	17.6	0	0
Organization Planning	41.2	47.1	5.9	5.9	0

Findings

Table 2 summarizes the author's 2008-2014 semi-structured interview data and shows the number of engineering managers and their desired staff competencies. Of the 10 PMBOK knowledge areas, only four are included as part of the core competencies. The percentages of engineering managers and their primary requirements included: 1) 100% required scheduling proficiency from the PMBOK Time Management knowledge areas, 2) 73% required planning proficiency from PMBOK Scope Management, 3) 60% required communication skills from PMBOK Skills, and 4) 40% required team building skills from PMBOK HR Management. The fieldwork further reinforced the current state of project management maturity primarily at Level 1 per the CMMI. Surprisingly, fieldwork documented that only one company utilized the earned value technique for project management, although the concepts involved are critical to project management and advancing through the maturity levels. Research results are listed in the Appendix Table A1, column 1, as "Staff Core Competencies." The technical skills and core competencies are mapped first to the PMBOK, second to EMBOK, and third to a "typical" project management textbook in the last two columns. Instructors are advised to teach the core competencies since this is what is desired of industry practitioners, then to add a subset of textbook topics based on their discipline.

From a project management tools perspective, fieldwork also showed Microsoft Project to be the predominant tool required, but established that it was generally misunderstood and misapplied. While practitioners often were able to create Gantt charts using MS Project, they rarely understand the interactions and impacts of the MS Project resource and calendar functions. This typically led to unexpected results, confusing output, and extreme frustration which typically led to a negative bias against project management software.

TABLE (2): ENGINEERING STAFF REQUIRED CORE COMPETENCIES BY MANUFACTURING INDUSTRY

Manufacturing Industry	Percent of Mgrs	Respondents per PMBOK Knowledge Areas			
		(5) Scope Mgt	(6) Time Mgt	(9) HR Mgt	(10) Comm
Consumer Goods	20	3	3	0	0
Industrial Product	60	5	9	4	6
Pharmaceutical	20	3	3	2	3
Totals	100%	11	15	6	9
Percent of Total		73%	100%	40%	60%

* PMBOK Chapters are shown in parentheses ( )

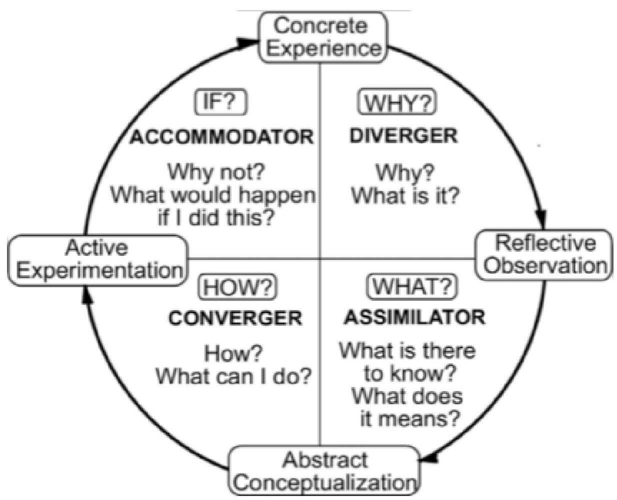
Educational Theory

There is little evidence of a standard, manufacturing-focused, project management pedagogy for undergraduates. Entry-level employees need to bring knowledge, skills, and abilities, but competencies are the result of experience (Gokhale, 2005). Competency is attained by knowledge acquired through training and skills, developed through experience via the application of acquired knowledge (Edum-Fotwe & McCaffer, 2000). Therefore, pedagogy founded in active learning is desirable for an undergraduate student demographic that has little or no hands-on experience. Kolb's experiential learning framework, learning styles, and learning cycle were adopted for this pedagogy because it is used to model how experience can be translated into conceptual competencies (Botelho, Marietto, Maria das Graças Bruno, Ferreira, João Carlos da Motta, & Pimentel, 2015).

Research shows that there is no single "best" teaching style, and students learn more effectively through a combination of hands-on and traditional approaches (McCrary, Peterson, & Strong, 2007). Kolb's Model, shown in Figure 3, was selected for this pedagogy to incorporate the lecture style needed for PMBOK and EMBOK concepts and the active learning needed to promote a better understanding of real-world application. Integration of textbook study and three student-team project simulations allows students to apply technical skills while providing a forum to practice soft skills. For this pedagogy, a project simulation is defined as student teams working through the integrated project management processes to develop a project plan and then fabricate progress.

Felder and Brent (2005) propose that the most effective utilization of the Kolb Cycle involves teaching around the cycle, which the multiple student-team project simulation assignments fulfill. However, a circular process needs a starting point, and the desired entry point is "experience and reflection," followed by repetition for reinforcement (Akella, 2010). Reflection is defined as the process of deriving meaning and knowledge from an experience (McCrary et al., 2007). In turn, "reflective observation" and "abstract conceptualization" are preparation for "active experimentation" and "concrete experience." The instructor takes on the role of motivator and expert for the learner types "diverger" and "assimilator," who are most suited for lecture and written assessments (Felder & Brent, 2005). Simulations are best suited for the "converger" and "accommodator." As such, this research proposes a pedagogy that creates a foundation of theory and technical tools, along with three project simulations for active, experiential learning.

FIGURE (3): KOLB'S EXPERIENTIAL LEARNING CYCLE (Botelho et al., 2015)



As indicated earlier, the goals of this study were to define a set of core project management competencies and to define a course structure for project management education to support a manufacturing shop-floor environment. The intended course proposal would position graduates to meet first year of employment expectations, while simultaneously providing education theory to take companies to the next level on the CMMI (IIL, 2016) for project management. The proposed approach incorporates textbook theory in parallel with active learning within simulated projects by student teams. The following subsections detail course objectives, structure, modules, and project simulations.

Pedagogical Approach and Course Structure

Course Objectives

The objective is to introduce project management techniques from the standpoint of developing and executing internal projects at the manufacturing shop-floor level within an industrial organization. Three critical project categories that frequently occur at the shop-floor level include planned maintenance shutdowns, manufacturing process improvements, and capital acquisition/installation projects. Specific objectives include students gaining competence in:

- Leading industrial project teams
- Communication and interpersonal skills
- Development and control of project scopes
- Planning and scheduling a project
- Risk management techniques for project management
- Execution and control of a project
- Communication planning and status reporting
- Status reporting and business/technical correspondence
- Project management software (Microsoft Project recommended)

Course Structure

The proposed structure, shown in Table 3, details a 15-week semester including: 1) a lecture based delivery of core competencies, 2) active learning project simulations, and 3) technical tools training. Table 4 details the core competencies for each of the three modules shown in Table 3 along with appropriate tools and templates. After the initial overview and communication module, competencies and tools are taught concurrently within a framework of three project simulations. The simulations represent the types of projects typically encountered at the manufacturing floor level: plant maintenance shutdowns, continuous improvement projects, and capital projects.

TABLE (3): SUGGESTED WEEKLY COURSE OUTLINE

Topic/Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Module	PM Overview and Communication		Planning and Scheduling							Monitoring and Control					
Project Simulation			Plant Maintenance			Continuous Improvement				Capital Procurement and/or Installation					
Technical Tools			Manual (Excel and Word)							Microsoft Project Software					

TABLE (4): SYLLABUS MODULES: CORE COMPETENCIES ONLY

Module	Core Competencies	Tools and Templates	PMBOK Chapters*	EMBOK Domain
Project Management Overview and Communication	• Leadership Skills • Interpersonal and Conflict Mgmt. • Meeting Mgmt. • Stakeholder Mgmt.	• Written Communication • Kick Off Meeting • Meeting Agendas	(9) Human Resources (10) Communication (12) Procurement (13) Stakeholder	
Planning and Scheduling	• Stakeholder Analysis • Scope • Work Breakdown Structure • Activity Sequencing and Scheduling • Resource Analysis • Communication Planning	• Scope Elaboration • Mind Mapping • Yellow Sticky Approach • Network Diagram • Responsibility Matrix • Communication Plan • WBS / OBS / RBS	(4) Integration (5) Scope (6) Time (11) Risk	Scope: 4.2.3.1 Budget: 4.2.3.3 WBS: • 4.2.1.1 • 4.2.3.2 • 4.3.1 / 2 Schedule: • 4.2.1.2 • 4.2.3.2 • 4.3.2
Monitoring and Control	• Progress Reporting • Scope Control • Closing/Lessons Learned	• Gantt Charts • Scope Mgmt.	(7) Cost (8) Quality	Earned Value 4.2.1.3 Scope Control 4.4.2

* PMBOK Chapters are shown in parentheses ( )

A flipped classroom approach is recommended during the project simulation, requiring students to read and be quizzed on textbook content outside of class. This allows more instructor time to lead student teams through the simulations, allowing students to ask clarification questions on textbook material. It drives learning points home through demonstration and completion of activities needed to run the simulations. To this end, beginning with Module 2, textbook chapter quizzes are treated as untimed worksheets, with deadlines prior to in-class process work. Instructors are required to have "same week" turnaround for feedback on key project aspects of scope, WBS, and progress reports. It should be noted that this pedagogy only addresses internal company projects for a manufacturing oriented operation. Material and methods related to external projects would be content added at an instructor's discretion. Additionally, the proposed pedagogy does not suggest assessments other than chapter quizzes and project simulation evaluations.

Module 1: Project Management Overview and Communication

As this pedagogy is intended to support the industrial technologist in a manufacturing environment, the supposition is that projects will be assigned to, rather than selected by, newly hired graduates. Thus, the recommended introduction should focus on defining project steps and leadership/organizational aspects as an overview; introductory topics such as project selection and portfolio management may be added at the end if time permits. Unfortunately, respondents to a survey by Papke-Shields (2010) in their research indicated that communication is one of three PM practices used least frequently (Papke-Shields, Beise, & Quan, 2010). Thus, the core competency targeted within this module is communication, which is also the project manager's main job responsibility (Gray & Larson, 2011).

PMBOK differentiates communication into three styles: pull, push, and, interactive (PMI, 2013). Pull information is the easiest to establish. It is defined as large volumes of information set and maintained by the project team in a repository manner site that stakeholders can access at will. Thus, SharePoint or other "cloud type" training is useful to add for students. Push information is specific information sent to specific users and, as such, is the most challenging. Push requires teaching stakeholder analysis and the art of written communication. Kerzner (2013) points out that sponsor-related information is different from project team-related information, a difficult concept to teach for those not indoctrinated to corporate organization and politics and, of course, vastly different depending on company culture. PMI provides multiple templates for project management; among them is a communication management template. The communication plan template includes input areas for: 1) the stakeholder matrix, 2) information required, 3) method of distribution, 4) distribution frequency, 5) person responsible to send information, 6) assumptions and constraints, and 7) glossary of terms.

In an age of text messages and Twitter, written and verbal communications are increasingly rare forms. Business writing must be emphasized through project status reporting; PMI has templates and the Purdue Online Writing Lab (Purdue University, 2016) has writing guides to support this. Verbal communication is reinforced through in-class role play for project kickoff meetings and status reporting as active learning exercises.

Module 2: Planning and Scheduling

The processes required to create a scope, produce a comprehensive WBS, and then sequence activities are core competencies within this module. A priority is imparting the need to understand the "why" of a project before the "what are we going to do" (Brown & Hyer, 2010). Scope exercises include both preliminary and final assignment submissions, with formal feedback on both. Students are advised to begin scope development early and are encouraged to submit draft copies to the instructor prior to deadlines. It is important to active learning for the instructor to be tolerant of errors on preliminary scopes, but to be critical when scoring final scope statements. PMBOK establishes six primary requirements for a project scope along with a template which includes the items in Table 5 (PMI, 2013).

Students have a difficult time grasping "progressive elaboration" whereby the scope is developed concurrently and iteratively with a work breakdown structure (WBS). A review of PMBOK and textbooks determined that "mind mapping" was a best practice, and it is a standard tool for WBS development (Brown & Hyer, 2003). Another key aspect of task definition is the importance of verbs to begin an activity definition (Brown & Hyer, 2010; PMI, 2013). A subtle revision in PMBOK 5e was a change to rename project management processes in "verb-noun" format. This provided a degree of anecdotal evidence of the need to impart clarity to an activity by starting with a verb (action word), and then having a noun describe the content required. Depending on project complexity, a network diagram produced via the precedence diagram method (PDM) may be required and is part of the course content. Construction of a network diagram is facilitated by project management software, which also allows students to ascertain technical aspects such as individual task start and finish times, the project critical path, and overall duration. When developing a precedence diagram, the activity on node (AON) method is recommended over activity on arrow or PERT. AON is the predominant methodology in textbook design (Brown & Hyer, 2010; Gray & Larson, 2011; Kerzner, 2013), default software settings, and fieldwork evidence. In real life, projects do not come with a list of predecessors as they do in textbooks. The recommended tool is to teach the "yellow sticky approach" (Brown & Hyer, 2010; Gray & Larson, 2011). Additionally, personal experience and fieldwork training has shown that the "yellow sticky approach" will generate a good deal of collaboration, buy-in, discovery of new activities, and updates to project scopes.

Once the project scope and WBS are generated, a communication tool is required for project coordination and management. A manual tool, rather than project software applications, is introduced in this module. The manufacturing environment industry standard is the responsibility matrix, also known as a Responsibility, Approval, Consult, Inform (RACI) chart. This tool will document the WBS by providing a list of activities needed and responsible individual(s). It is one of the fundamental organization methods for use on short-term projects with defined deadlines. Completing the communication for Module 1 is defining and creating the Gantt chart. It is taught in Module 2 via manual (Excel) format, and as a standard output from project management software in Module 3. Finally, risk management as a major planning component must not be neglected (Kerzner, 2013). Risk management will be a part of the textbook pedagogy, and may be part of the active learning at the instructor's discretion.

TABLE (5): PMBOK PROJECT SCOPE REQUIREMENTS

Scope Requirement	Description
Project Description and Objectives	• Developed by progressive elaboration • Characterizes the result of the project by defining the "what and when" • Project milestones (not in PMBOK, but recommended)
Acceptance Criteria	• A set of conditions required for acceptance of deliverables
Deliverables	• Any unique and verifiable product, result, or capability to perform a service • Ancillary reports and documentation
Project Limits and Exclusions	• Identifies project boundaries • Specifies what is excluded from the project in order to manage stakeholder expectations
Constraints	• Internal and external limiting factors affecting the project execution or processes • May include budget, imposed dates (deadlines), schedule milestones • Contractual agreements for external projects (if applicable)
Assumptions	• A factor assumed to be real that impacts planning • Explains the impact if an assumed factor proves to be false (not real) • Must be identified, documented, and validated during scope development

Module 3: Monitoring and Control

Monitoring and control of projects may be comprised of several tools and techniques, such as Gantt charts, control charts, or the earned value (EV) method. The Gantt chart is the predominant control and reporting tool and is part of project software output in this module. Control charts, typical of textbook content, were not observed in fieldwork and not addressed herein. The other required tool within this module is EV, as students must be aware of budget consumption relative to work progress. In keeping with the underlying communication focus of this proposed pedagogy, standard reporting methods are also a core competency for this module. While PMI provides a reporting template, it is much too basic for industrial use and needs to be adapted to individual course requirements. Therefore, a key aspect in this module's simulation is for project teams to develop standard reporting forms. This also requires students to practice and apply stakeholder analysis and creation of a communication matrix.

Other core competencies in this module include scope control to prevent scope creep, project crashing, and a formalized process for project closure and lessons learned. All of these topics should be included as part of the textbook reading, and may be introduced in the simulations at the instructor's discretion. Scope creep may be assessed from the status reports generated for the simulations. Project crashing may be introduced in the final project simulation of this module by creating an imposed deadline after scope approval. Lessons learned may be introduced on an individual simulation basis or as a preferred semester assignment to have students summarize lessons gleaned from executing all three of the simulated projects.

Microsoft Project is the preferred software tool to introduce into this module. Software trial licenses and training videos are typically provided by textbooks. Additionally, commercial training from providers such as Lynda.com are exceptional tools. As a caveat to Microsoft Project instruction, a critical teaching point is to include the interaction effect between "resources" and "activities." Once resources are input into a WBS, the complexity of the software increases, considering different definitions for duration, hours, and work. Also, calendar functions for resources, tasks, and the project are challenges to new users. Faculty must carefully consider their own ability to preclude misuse of the software.

Project Simulations

Three project simulations, as shown in Table 3, are recommended. The first project, plant maintenance shutdown, should be coordinated using a RACI chart or a responsibility matrix. The second project, for continuous improvement, would utilize either the A3 storyboard format or Excel-based Gantt charts. The third project, for capital or an enhanced version from the continuous improvement project, would employ project software (recommended). Students are expected to produce forms and templates where needed for core competencies, including communication plans, meeting agendas, progress reports, close out/lessons learned, etc.

Project teams of three students are recommended, with rotating managerial, planning, and communication duties. As teams are tasked to select a real world company for simulated projects, it is recommended that students self-select their teammates to align common degree disciplines and interests. Teams will execute the three projects sequentially, adopting additional core competencies and modifying methods as the course progresses. Accordingly, assignments are structured with increasing requirements. For example, the first project is structured to end after completion of the scope and WBS. The second project takes the simulation to the next step, having student teams draft and create a status report form. The third project adds at least one status report and Gantt chart update. Instructors may introduce an imposed project deadline, budget cut, or scope change to interject additional reality.

Implications

As demonstrated by the comparison of the 1997, 2006, 2009 research articles and the 2008-2014 fieldwork, it is apparent that project management is still mostly executed by ad hoc processes and is applied inconsistently throughout the manufacturing industry. The mapping of project management textbooks to PMBOK knowledge areas implies that the goal of course work is to educate students to the PMBOK, rather than on the fundamentals needed to manage projects. While the two are linked, it is necessary to recall that the PMBOK is not a "how to" manual, but rather a collection of requirements for knowledge area expertise. The mapping between PMBOK and textbook may temp instructors to cover all knowledge areas, but the results of studies on project management maturity find that the goal of project management proficiency is not being met. Further, PMBOK is a guide book for experienced professionals to reference and validate their expertise via Project Management Professional (PMP) certification. A four-year degreed professional still requires 4,500 hours leading and directing projects to become a PMP. Hence, it may not be in our students' best interests to include the entire breadth of the PMBOK knowledge areas. Given the current state of project management maturity at Level 1 per the CMMI, higher education should focus on core project management skills rather than exposing students to all aspects of the PMBOK.

The core project management competencies sought by manufacturing engineering managers for their staff are focused into four of the ten PMBOK knowledge areas: scope, time, HR management, and communication. Omitted knowledge areas include project management integration, resource management, quality, risk, procurement, and stakeholder satisfaction. The implication is that project managers recognize the limited abilities of their staff, as evidenced by the Level 1 maturity, and are seeking a "return to fundamentals" to establish critical project management processes. In the competitive world of collegiate publishing, textbooks typically have more chapters than there are weeks in a semester and project management texts tend to map to the PMBOK as a measure of their credibility. While not directly stated, the underlying concern is that with the rise and significance of PMI certifications, there may have developed a tendency by faculty to try to teach too diverse a set of concepts, inhibiting the requisite skill development.

Thus, the pedagogical goal of this paper is to re-focus the undergraduate project management curriculum down to a core set of knowledge areas and, through active learning and repetition, to develop a level of competency required by our graduates' early career managers. The proposed pedagogy is intended to guide professors to develop deeper understandings on a narrower scope of PMBOK knowledge areas, that those being the content areas dealing with scope definition, planning, work breakdown structure development, (scope management), activity sequencing, milestones, scheduling, developing and sequencing tasks (time management), team building, (HR management), and communication. As scope and WBS development are critical to project success, repetition via three simulation exercises provides active and experiential learning. The focus on communication throughout the pedagogy reinforces the overarching role of a project manager.

The other six PMBOK knowledge areas are still important, but need to be introduced as appropriate to time constraints and core concept proficiency development. The key to continuous improvement of project management pedagogy is active tracking of the tools utilized by practitioners, while staying abreast of new trends and techniques. Future study will be based on surveys to alumni mailing lists to determine the tools being used by graduates in the first five years of employment. This will provide twofold information: 1) what are the relevant knowledge areas in demand, and 2) how effective is the pedagogical approach to meet these needs?

Summary

The challenges in teaching project management in higher education is are that there is an extremely diverse content availability and no uniform definition of an "ideal" project structure (PMI, 2013). A well-designed undergraduate project management class must introduce students to a wide range of practices and tools, providing theory and discipline relevancy, but also developing core competencies to allow new graduates to apply project management skills at the onset of their career. Additionally, graduates should be able to apply their skills and theoretical knowledge to improve an organization from CMMI Level 1 to CMMI Level 2 or 3 maturity.

The pedagogy presented herein supports the wants and needs of managers who will recruit applied engineering graduates. Proposed is a "core competency" approach for undergraduate project management courses based on PMBOK and EMBOK-related techniques and tools needed by engineering managers of manufacturing operations. To provide a comprehensive project management education experience, core competencies may be supplemented with other knowledge areas than those recommended, but not at the expense of developing core proficiencies. Appendix Table A1 establishes the core engineering staff competencies currently in demand for manufacturing companies and maps related content currently available from popular project management textbooks. This allows for discipline-specific concepts to be included and meet any ATMAE-related requirements.

Through the pedagogy presented, new graduates will be more marketable and have a better chance to apply an appropriate degree of rigor for project management tools and techniques, while providing leadership to team members with more years of experience. Ideally, this course would be delivered in the first semester of a student's junior year, and then the techniques required for semester projects in subsequent courses. It is important to realize that the course goal is not to produce PMI certified graduates or serve as a PMP exam review course. That said, the provided pedagogy is mapped to the PMBOK, providing graduates a frame of reference for pursuing the Certified Associate in Project Management (CAPM) from PMI and beginning the path toward PMP certification.

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Appendix

TABLE (A1): ENGINEERING STAFF NEEDS MAPPED TO PMBOK, EMBOK AND TEXTBOOK CONTENT

Staff Core Competencies	PMBOK Knowledge Area*	EMBOK PM Techniques	Instructor Discretionary Related Content	
• None	(4) Integration	4.2 PM Techniques 4.2.1 Fundamentals and Strategies: WBS, Schedule, EV Analysis	• Stakeholder Register • Statement of Work • Business Case	• Project Charter • Change Request Logs • Forecasts
• Define Scope • Create Work Breakdown Structure (WBS) • Validate (Approve) Scope	(5) Scope Management	4.2.3 Scope, Schedule, Budget .1 Scope .2 Scheduling • WBS 4.3 Scheduling .1 WBS Table .2 Effective WBS 4.4.2 Adapting to Changing Customer Needs	• WBS Dictionary	• Scope Change Control
• Define and Sequence Activities • Developing Milestones • Create Network Diagram • Develop Schedule • Schedule Network Analysis	(6) Time Management	4.2.3 Scope, Schedule, Budget .2 Scheduling • Network • CPM • Gantt • Resources .3 Budgeting 4.3.2 Work Scheduling	• Bottom Up and/or Top Down Estimating of Resources and Durations • Earned Value Rules • 3 Point Estimating (PERT) • Reserve Analysis (Time Buffers)	• Resource Breakdown Structure (RBS) • Critical Chain Method • Resource Leveling • Crashing and Fast Tracking • Leads and Lags • What If Analysis • Simulation
• None	(7) Cost Management (Resources)		• Estimating topics from "Time" are repeated here • Earned Value Management (EVM) • EVM Forecasting	• HR Mgt Plan • Vendor Bid Analysis • Budgets and Mgt Reserves

Staff Core Competencies	PMBOK Knowledge Area*	EMBOK PM Techniques	Instructor Discretionary Related Content	
• None	(8) Quality	4.5 Total Quality Mgt 4.5.1 Industry Standards 4.5.2 Other Than TQM .1 Process Mgt Tools .2 Other Tools: Six Sigma Kaizen. FMEA, QFD 4.6 Project/Process Tools 4.6.1 RCA Analysis 4.6.2 Problem Response	• Cost of Quality • 7 Basic Quality Tools • Quality Assurance Tools	• Statistical Sampling • Design of Experiments • Benchmarking
• Development of Team	(9) Human Resource Management	4.2.5 Project Plan Concepts and Tools .1 Successful Project • Teamwork • Managing • Leading .2 Potential Failure	• Organizational Theory • Negotiating • Virtual Teams • Training • Building Trust	• Interpersonal Skills • Performance Appraisal • Conflict Management
• Communication Plan	(10) Communication	4.6.3 Project Management Software	• Information System Management	• Communication Model
• None	(11) Risk	4.2.4 Assess Project Risk .1 Financial .2 Environmental and Legal 4.6.4 Simulation	• SWOT Analysis • Risk Categories • Risk Assessment • Risk Probability and Impact Matrix	• Quantitative Risk Analysis • Strategies and Contingencies
• None	(12) Procurement		• Types of Contracts • Statement of Work • RFI, RFP, RFQ, IVB	• Negotiations • Purchase Agreements
• None	(13) Stakeholder	4.4 Maintaining Customer Service and Satisfaction .1 Customer Feedback .2 Measure Satisfaction	• Stakeholder Analysis • Interpersonal Skills	• Management Skills

* PMBOK Chapters are shown in parentheses ( )