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Manufacturing and Non-Manufacturing Students' Perceptions on the Applicability of the Four Pillars

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Introduction

The Four Pillars of Manufacturing Engineering was developed and supported by the Society of Manufacturing Engineers (SME), the Association of Technology, Management, and Applied Engineering, (ATMAE), and the Accreditation Board for Engineering and Technology (ABET). A group of manufacturing educators created it in 2011 as part of a strategic plan to reverse negative trends in manufacturing education and improve manufacturing competitiveness (Mott, Raju, & Stratton). The Four Pillars consist of foundational knowledge areas that represent a typical Manufacturing Engineer's Body of Knowledge. In addition, it provides the recommended content for academic programs related to manufacturing and articulates the fundamental knowledge required by manufacturing engineering professionals.

The concept of the Four Pillars is to design curricula that provide adequate academic preparation for students seeking gainful employment in manufacturing or manufacturing-related firms. While the Four Pillars could prove useful in addressing the gaps in existing manufacturing programs as it requires the development of rigorous instructional materials for use in classrooms, laboratories, and projects, the extent of the academic preparation could also be applicable to non-manufacturing programs. Thus, the theory tested in this research is that the Four Pillars Manufacturing Engineering is applicable to more than just manufacturing programs. The Four Pillars knowledge areas are relevant across a broad spectrum of technical-managerial disciplines.

ATMAE accredited educational programs emphasize a mix of technical and managerial skill sets. The applied nature of the curriculum typically distinguishes ATMAE programs from pure engineering and business programs. The required knowledge and competencies for an entry-level technical manager are important. The required competencies and knowledge of a manufacturing engineering manager are thought to be closely related to the required competencies and knowledge for an entry-level technical manager. ATMAE accredited programs include both manufacturing and non-manufacturing programs such as drafting, construction, and computer networking.

The technical education received by students in ATMAE accredited programs in four-year institutions should prepare students for entry-level technical-managerial positions in industry. This research sought to capture the perceptions of alumni, students and faculty across multiple programs, both manufacturing and non-manufacturing related. Using the Four Pillars manufacturing engineering foundational knowledge areas, the research addressed the following:

- What fundamental knowledge areas are most important for an entry-level technical manager?
- What fundamental knowledge areas are or were covered in (your) respective major program?
- What additional important competencies should be covered in (your) major field?
- Are the knowledge areas specified by the Four Pillars model applicable to non-manufacturing areas of study?
- Are the knowledge areas specified by the Four Pillars model congruent with what is being taught and what is perceived as important for non-manufacturing programs?

Literature Review

Lowden, Hall, Elliot, & Lewin (2011) assessed the perceptions of employers and higher education institutions with regard to graduates' employable skills and knowledge. All organizations expect graduates to possess both the technical and discipline-related competencies of their acquired degrees. Employers also expect graduates to have skills such as teamwork, leadership, communication, critical thinking, and problem solving abilities. Educational programs that produce these types of graduates who have both experiential and work-related learning are likely to thrive.

Slota (2011), an educational applications engineer, asserted that non-manufacturing students are being exposed to computer integrated manufacturing environments without even knowing it. Computer-aided design (CAD) and computer-aided manufacturing (CAM) software are used in departments that don't necessarily teach manufacturing skills. The Radio Astronomy Department at the University of Massachusetts uses this software to design and build their own mesoscale research components. Large numbers of students may be engaged in manufacturing who might not realize it. Manufacturing labs on campuses are being used for non-manufacturing purposes such as Auburn University where CAM software is used for research in material science and exotic materials formation.

As far back as 1993, the Institute of Management Services found that traditional ways of working were becoming obsolete, as high-quality lean and just-in-time production required a more highly skilled and flexible work force. Companies found they needed to pay this new type of worker based on their skill sets rather than their job title. This skill-based pay structure gained significant acceptance and is being used now in both manufacturing and non-manufacturing environments.

Duverger (2012) found that voice-of-the-customer techniques, used extensively in the manufacturing industry, could also be used to produce viable ideas in the context of service innovation. One such technique is electronic brainstorming (EBS), which is used for gathering innovative ideas. EBS allows participants to stay anonymous and suggest ideas using asynchronous web-based mediums to increase participation and reduce and fear of evaluation.

Using survey research and case studies, Antony, Coleman, Montgomery, Anderson, and Silvestrini (2011) built a strong argument for the use of design of experiments (DOE) in non-manufacturing areas. DOE has been widely applied in manufacturing, but its use is not well documented in other areas. The potential application of DOE in service environments include key service process and design variables that influence system performance; response time to customer complaints; errors on service orders; service delivery time in banks and restaurants, and patient report turn-around time in healthcare. The actual benefits of DOE were reported in a utility company, an accounts receivables department, information technology services, a hospital, a web-based retailer, and a financial services company among others. DOE was used to reduce data entry errors, speed debt collection, and improve emergency department performance.

The control charts used primarily in manufacturing have the potential to be applied to many different areas, especially non-manufacturing and service sectors such as supply chain management, security, office administration, disaster management, and the health care industry. In a series of articles, researchers from Singapore, China, UAE, and France proposed the use of the G, TC, GCUSUM, TC-CUSUM control charts to monitor a critical event through the simultaneous testing of its time interval (T) and magnitude (C or X). These charts are more effective for detecting the out-of-control conditions, particularly for those in the service sector where responsiveness is important (Wu, Liu, He, & Khoo, 2010; Yafen, Zhen, Shamsuzzaman, & Zhang, 2010; Qu, Wu, Khoo, & Castagliola, 2013; Qu, Wu, Khoo, & Shu, 2014).

Broad-based, applied learning is a distinctive characteristic of ATMAE manufacturing programs. Knowledge and understanding of manufacturing-related competencies can be useful for non-manufacturing programs. This research sought to capture perceptions about that knowledge and its applicability to programs other than manufacturing.

Methodology

This survey research measured the perception of importance and coverage of the Four Pillars of Manufacturing Management Knowledge as applicable across all major programs in ATMAE accredited department at a comprehensive university. The survey was sent to students, faculty and alumni of advanced manufacturing (AM), construction management (CM), technology management (TM), computer information technology (CIT), industrial education (IE), architectural sciences (AS) and master of science (MS) programs. The responses from each of the programs were compared.

The survey instrument was a modified version of an instrument previously used to collect the perceptions of AM majors with regard to Four Pillars foundational principles applicability to their degree program. Program faculty and alumni reviewed the instrument for face validity. The survey listed 32 of the knowledge areas from the Four Pillars Manufacturing Engineering model. Of the 32 knowledge areas, 14 were from the foundation knowledge area of manufacturing management. The other 18 items were selected from each of the other foundational areas, except mathematics and science, as these are required for all majors in the college. The questions on the survey were the same as the ones given to manufacturing students on the previous study except that all references to manufacturing or production were removed. For example, one of the Four Pillars knowledge areas is Production and Process Planning. This was changed to Process Planning. In addition, the title of the survey was changed from Perceptions of Manufacturing Management Knowledge and the Four Pillars to Perceptions on the Four Pillars of Knowledge.

Respondents were asked to rate each knowledge area twice using a Likert scale from 1 to 5 or "not applicable". For the first set of the 32 knowledge area questions, respondents ranked how they perceived the item's importance with 5 being very important and 1 being not important. In the second set of the 32 knowledge area questions, the respondents ranked how they perceived the item was/is covered in their respective programs. A response of 5 indicated the item was covered comprehensively with 1 representing little to no coverage.

An electronic version of the survey was created using Qualtrics software, an institutionally approved survey package. The population of participants was all majors across all programs in the department. Invitations and consent forms were sent in early April of the spring semester via email to current students, faculty, and recent alumni. A second request was sent one week later with a final request sent seven days thereafter. The invited students included both graduate and undergraduate levels. The total survey population was approximately 600 students, 12 faculty, and 15 alumni. The total number of surveys completed was 86, a response rate of approximately 14%. All collected responses were anonymous. The data was compiled, sorted, and analyzed using descriptive statistics.

Results and Discussion

Overall perceptions of survey participants

A chi-square test of independence found that the responses on the questions for all the Four Pillar knowledge areas had no significant differences. Figure 1 shows the summary of all the responses from all majors. The mean values of responses for questions 1 (Q1) and 2 (Q2) are plotted. The figure shows that most of the key topics from the Four Pillars were perceived as important for an entry-level technical manager. The mean values for all the responses were 3 and above (ranging from 3.2 for materials handling and packaging to 4.52 for problem analysis and solving). The five most important key requirements for an entry-level technical manager perceived by all participants was problem analysis and solving (4.52), interpersonal skills (4.47), safety (4.47), project management (4.44), and written and oral communication (4.38).

In response to Q2 "what knowledge was/is covered in your program", the mean values were lower compared to Q1. Participants did not perceive that all the important topics were covered comprehensively. For the majority of the important topics, the mean value of Q2 was lower than Q1, except materials, materials handling and packaging, and power systems. Several topics had similar means for Q1 and Q2 that indicated agreement on the balance of importance and offerings. Those key topics were engineering science, lifecycle analysis, design management, process research and development, control systems, quality systems and standards, operations research, and supply chain and logistics. However, none of those were considered most important for an entry-level technology manager. The top five key topics perceived covered comprehensively by all majors were project management (4.14), problem analysis and solving (4.03), quality systems and standards (4), education and training (3.97), and materials (3.92). One important observation is that among the five most covered topics, two were perceived as the most important requirement for an entry-level technology manager; problem analysis and solving and project management. Several topics had large differences between the mean values of Q1 and Q2, indicating areas of improvement. Those were interpersonal skills (Q1: 4.47, Q2: 3.38), written and oral communication (4.38, 3.83), human factors (4.19, 3.17), safety (4.47, 3.77), strategic planning (4.17, 3.53), personnel management (4.34, 3.48), human behavior and leadership (4.18, 3.41), labor relations (3.7, 3.09), ethics (4.31, 3.43), and social responsibility (4.14, 3.2).

Perceptions between manufacturing (AM) and non-manufacturing students

Table 1 shows the top five topics perceived as important for an entry-level technical manager by students from each major. No responses were received from IE majors. There are more similarities compared to the differences. For example, all majors considered safety important. All majors, except CIT, considered written and oral communication important. Four out of the six majors perceived project management and problem analysis and solving as important. Standard, laws, regulations and ethics were found important by AM and CM majors. Besides similarities, there were some differences in the perceptions of AM and non-manufacturing. It was found that only AM perceived quality systems and standards as one of the top five. Interpersonal skills were selected as one of the top five by TM, AS and CIT, but not by AM. MS and CIT perceived ethics as one of top five, whereas other majors did not. However, the most important finding from Table 1 is that all majors considered similar topics important for an entry-level technical manager.

Figure 2 also represents the similarities and differences between the perceptions of AM and non-manufacturing on the requirement for entry-level technical manager. In Figure 2, the ratings of top 5 topics perceived by AM were plotted against the ratings of those perceived by other majors. It can be realized from Figure 2 that other majors disagreed with AM on quality systems and standards, and standards, laws and regulations as most important requirements for an entry-level technical manager. Although, most of the topics indicated in Figure 2 were perceived as top 5 key requirements by other majors as well, there were variations in the ratings among various groups, indicating differences in the perception level as well as relative importance of the topics. Problem analysis and solving, and safety were the two key topics with less variation in ratings, as revealed from Figure 2.

Table 2 shows the perceptions of AM and non-manufacturing majors on Q2 listing the top five topics perceived as not covered comprehensively in their curriculum. There were similarities in the responses as observed from Table 2. Social responsibility (4 times), labor relations (4), human factors (4) and global competition (2) were indicated by AM and other majors. Accounting/finance/economics and human factors were mentioned three times by other majors whereas as control systems, interpersonal skills, and human behavior/leadership were mentioned two times each. However, one important observation from the mean values of Table 1 is that most of the topics perceived not covered comprehensively in Table 2 are also perceived less important. Human behavior/leadership was perceived as both important and not covered by CM. Safety was perceived as both important and not covered by CIT. Table 2 also indicates several areas not in the top five of importance that different majors perceive are not comprehensively covered in their course curriculum. Those are social responsibility for AM, TM, MS and CIT, human factors for AM, MS, CM and CIT, labor relations for TM, MS, and CIT, and interpersonal skills for MS and CM programs.

Analysis of participants' comments

Besides the ratings, the participants were encouraged to provide additional topic areas not listed in the survey or additional comments. Some of the additional areas listed by the participants were estimating, scheduling, company management, computer software, studio projects, and structural design. These topics were closely related to the majors of the respective program. Suggested topics that could be considered across all programs were accountability, quality, research and hands-on experience. In the comments section, the participants commended the department for conducting the survey research and for providing them with most of the skill sets necessary for their career. One comment suggested that the reason Bill Gates dropped out of school was a lack of developing his interests that the programs develop curriculum that provides hands-on training and research opportunities.

Conclusions

The students, faculty and alumni across all majors perceived that the important requirements for an entry-level technical manager were safety, written and oral communication, project management, and problem analysis and solving. Non-manufacturing majors also highly ranked interpersonal skills, personnel management and ethics. Topics perceived by all majors as least covered in the curriculum were labor relations, social responsibility, and human factors. Non-manufacturing majors also perceived accounting/finance/economics and interpersonal skills as least covered.

There were more similarities than the differences in the perceptions of AM and non-manufacturing majors. Most majors' perceived similar skill sets as important for an entry-level manager. Safety was perceived important by all majors. Written and oral communication was perceived in the top five of importance by all majors except CIT. Project management and problem solving and analysis were also two topics ranked highly by majors. One of the major differences in the perceptions was that AM majors perceived quality systems and standards, and standards, laws, regulations as key requirements, which other majors didn't perceive. There were also similarities in the topics perceived least covered. Social responsibility, labor relations, and human factors were ranked highly by both AM and non-manufacturing majors.

Limitations of the research were high standard deviation (SD) values for almost all of the 32 survey items. The SD for Q2 was higher than Q1 indicating greater perception differences of the knowledge covered in curriculum. Moreover, the level of ratings provided by each major varied based on their perceptions.

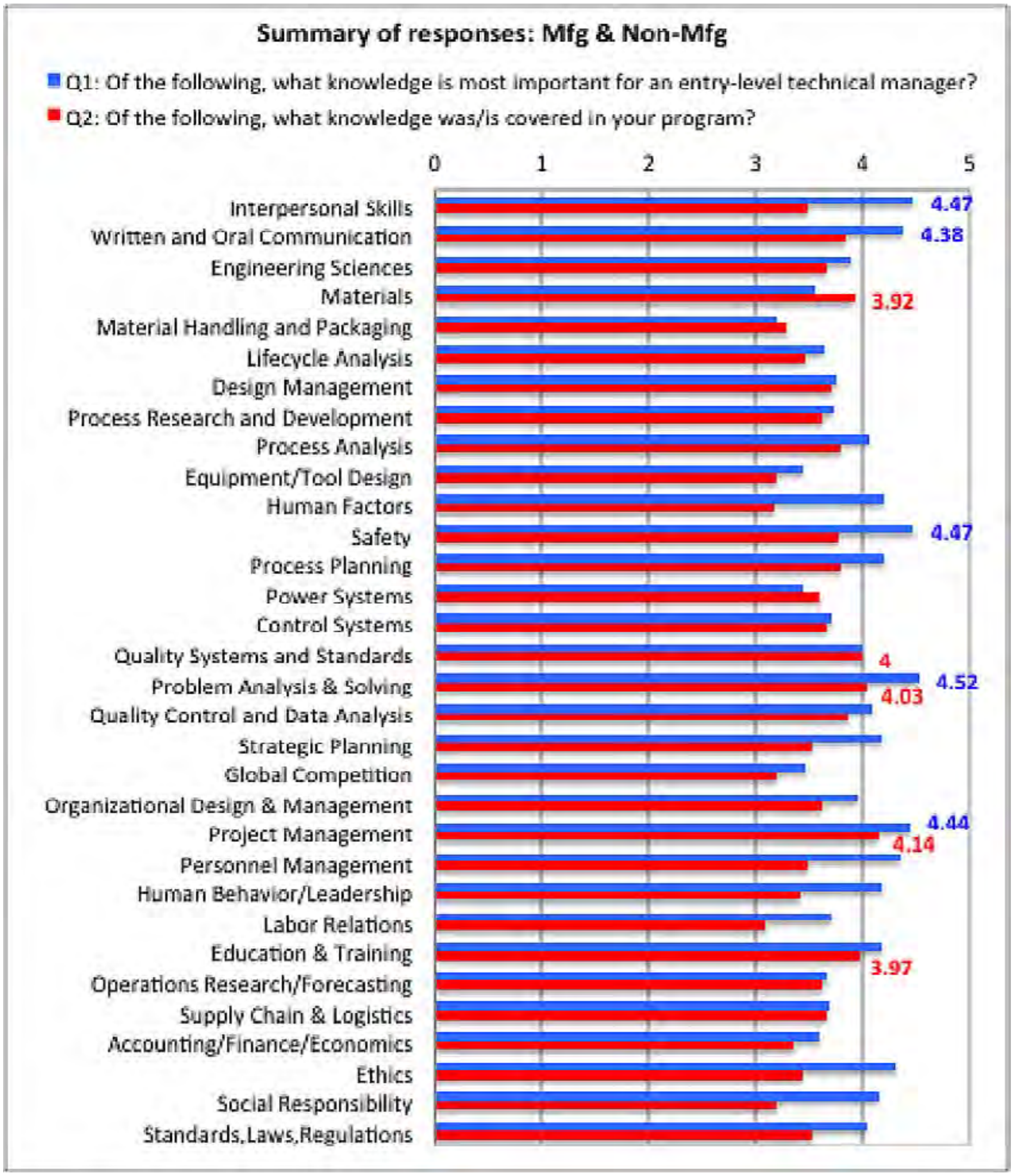

Figure 1. Bar chart showing the mean value of ratings for 32 Four Pillars key topics in response to the two questions sets.

Table 1: Top five topics perceived as important for an entry-level technical manager for all majors. Mean values shown in parentheses (Q1/Q2).

AM	TM	MS
Problem Analysis & Solving (4.25/2.83) Quality Systems and Standards (4.14/3.33) Safety (4.13/3.5) Standards, Laws, Regulations (4.13/2.5) Written and Oral Communication (4.0/2.83) Project Management (4.0/3.33)	Written and Oral Communication (4.69/4.46) Safety (4.69/4.15) Personnel Management (4.69/3.92) Project Management (4.62/4.54) Interpersonal Skills (4.62/4.31)	Problem Analysis & Solving (4.68/4.04) Project Management (4.52/4.35) Safety (4.52/3.52) Written and Oral Communication (4.47/4.17) Ethics (4.45/3.78)
AS	**CM**	**CIT**
Education & Training (4.67/3.8) Problem Analysis & Solving (4.56/4.2) Interpersonal Skills (4.4/4.0) Written and Oral Communication (4.4/3.83) Safety (4.4/4.17)	Written and Oral Communication (4.8/3.4) Project Management (4.8/5.0) Safety (4.6/4.6) Standards, Laws, Regulations (4.6/3.6) Human Behavior/Leadership (4.6/2.8)	Interpersonal Skills (4.64/3.56) Personnel Management (4.55/3.28) Problem Analysis & Solving (4.45/4.0) Safety (4.36/3.22) Ethics (4.36/3.39)

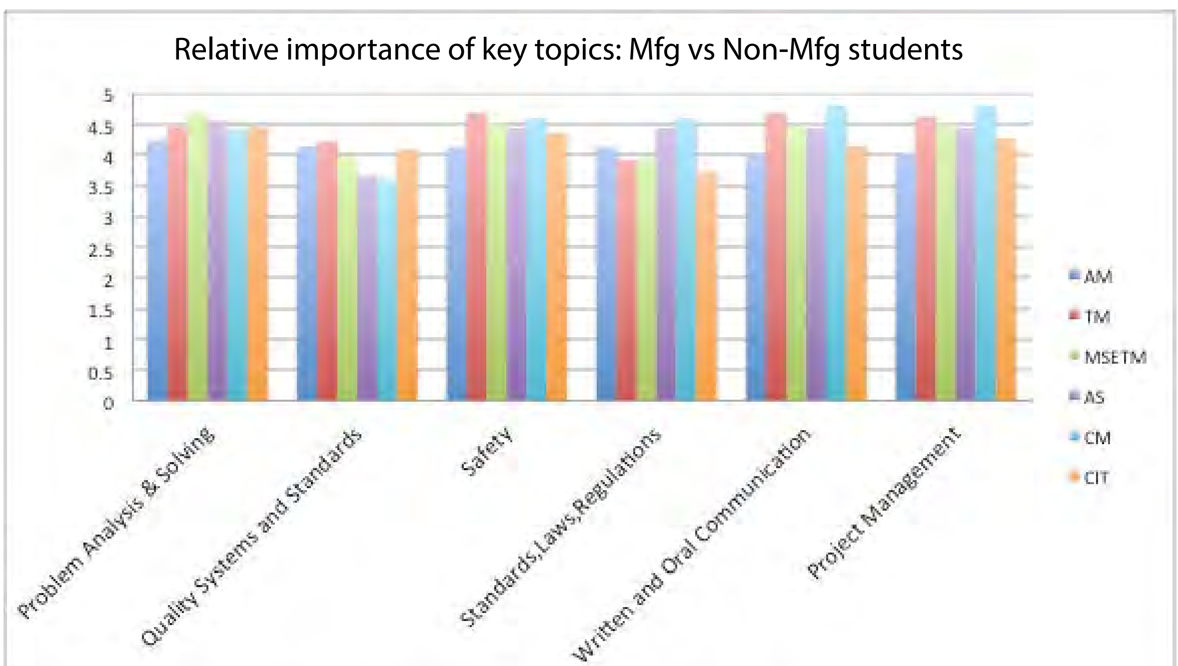

Figure 2: Relative importance of top five key topics selected by AM majors to other majors.

Table 2: Five topics perceived least covered in the curriculum compared to their importance for all majors. Mean values shown in parentheses (Q2/Q1).

AM	**TM**	**MS**
Labor Relations (2/3.88) Social Responsibility (2/4) Global Competition (2/3.86) Human Factors (2.17/3.5) Design Management (2.17/3)	Social Responsibility (3.69/4.15) Material Handling and Packaging (3.69/3.77) Human Behavior/ Leadership (3.69/4.23) Equipment/Tool Design (3.83/4.15) Labor Relations (3.85/3.85)	Social Responsibility (3.13/3.97) Labor Relations (3.13/3.74) Human Factors (3.17/4.16) Global Competition (3.43/3.39) Interpersonal Skills (3.45/4.42)
AS	**CM**	**CIT**
Lifecycle Analysis (2/3.56) Accounting/Finance/Economics (2.4/3.89) Supply Chain & Logistics (2.6/4.11) Control Systems (2.6/3.56) Power Systems(2.6/3.56)	Interpersonal Skills (2.6/4.6) Human Factors (2.75/5) Accounting/Finance/Economics (2.8/3.6) Control Systems (2.8/4.4) Human Behavior/Leadership (2.8/4.6)	Labor Relations (2.78/3.68) Human Factors (2.83/4.05) Accounting/Finance/Economics (2.89/3.5) Social Responsibility (3.22/4.09) Safety (3.22/4.36)

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Appendices

Table A1

What knowledge is most important for an entry-level technical manager?

Topic	Mean	SD	Responses
Interpersonal Skills	4.47	0.7	95
Written and Oral Communication	4.38	0.89	95
Engineering Sciences	3.89	0.94	96
Materials	3.56	1.02	94
Material Handling and Packaging	3.2	1.12	95
Lifecycle Analysis	3.63	0.97	96
Design Management	3.76	0.98	96
Process Research and Development	3.72	1.07	96
Process Analysis	4.06	0.77	95
Equipment/Tool Design	3.44	1.1	94
Human Factors	4.19	0.8	96
Safety	4.47	0.82	96
Process Planning	4.2	0.78	95
Power Systems	3.44	1.17	96
Control Systems	3.7	1.12	96
Quality Systems and Standards	3.99	0.94	95
Problem Analysis & Solving	4.52	0.79	96
Quality Control and Data Analysis	4.09	0.84	95
Strategic Planning	4.17	0.88	95
Global Competition	3.47	1.15	93
Organizational Design & Management	3.95	0.98	95
Project Management	4.44	0.83	96
Personnel Management	4.34	0.89	96
Human Behavior/Leadership	4.18	1.02	96
Labor Relations	3.7	1.07	96
Education & Training	4.17	0.91	94
Operations Research/Forecasting	3.67	1.05	96
Supply Chain & Logistics	3.68	1.08	96
Accounting/Finance/Economics	3.6	1.05	96
Ethics	4.31	0.98	96
Social Responsibility	4.14	0.97	96
Standards, Laws, Regulations	4.04	0.99	96

Table A2

What knowledge was/is covered in your program?

Topic	Mean	SD	Responses
Interpersonal Skills	3.48	1.31	75
Written and Oral Communication	3.83	1.15	77
Engineering Sciences	3.66	1.35	76
Materials	3.92	1.32	77
Material Handling and Packaging	3.29	1.59	76
Lifecycle Analysis	3.46	1.47	76
Design Management	3.71	1.28	77
Process Research and Development	3.62	1.35	74
Process Analysis	3.8	1.22	76
Equipment/Tool Design	3.2	1.62	76
Human Factors	3.17	1.49	75
Safety	3.77	1.49	77
Process Planning	3.79	1.28	76
Power Systems	3.6	1.7	75
Control Systems	3.67	1.57	76
Quality Systems and Standards	4	1.3	76
Problem Analysis & Solving	4.03	1.1	76
Quality Control and Data Analysis	3.86	1.21	76
Strategic Planning	3.53	1.3	76
Global Competition	3.2	1.57	74
Organizational Design & Management	3.61	1.17	77
Project Management	4.14	1.13	76
Personnel Management	3.48	1.37	75
Human Behavior/Leadership	3.41	1.42	76
Labor Relations	3.09	1.6	76
Education & Training	3.97	1.37	76
Operations Research/Forecasting	3.62	1.48	76
Supply Chain & Logistics	3.66	1.54	76
Accounting/Finance/Economics	3.36	1.6	76
Ethics	3.43	1.39	76
Social Responsibility	3.2	1.41	76
Standards, Laws, Regulations	3.53	1.43	76