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Survey of Manufacturing Company Expectations Based on the SME Four Pillars of Manufacturing Knowledge

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Abstract

Survey results are presented that identify and compare industry and academic perspectives of topics in a curriculum model based on the Four Pillars of Manufacturing Knowledge that a incorporates topics from the Society of Manufacturing Engineers Body of Knowledge for Certification of Manufacturing Engineering and Technologists with accreditation criteria. The model divides the broad field of Manufacturing Engineering into teachable divisions aligned to industry needs. The survey results indicate there is a good match between the model and expectations. In addition, the survey identifies higher priority manufacturing topics for education, and provides insights into how different types of academic programs prioritize the various topics of manufacturing.

Introduction

Manufacturing in the United States is increasingly being recognized for its importance. Federal policies, strategies, and funding are increasing for manufacturing education and training, research, and innovation centers to expedite the movement of lab concepts to production practices. It comes at a time when industry is experiencing shortages of talent to meet current demand, and faces eminent retirement of many of its technical and engineering workforce that will fuel future demand. In the SME "Workforce Imperative: A Manufacturing Education Strategy" white paper, recommendations are made to ensure preparation of existing and future workforce. These include working together to attract students into manufacturing, articulate a standard core of manufacturing knowledge, improve manufacturing curriculum, integrate manufacturing into STEM education, develop faculty, and strategically deploy resources.

This paper describes the results of an online survey that was distributed to a broad audience including managers, company owners, engineers, educators and education administrators. The objective of the survey was to evaluate the relative importance of a common core of manufacturing topics identified in the SME Four Pillars of Manufacturing Knowledge (SME, 2012) which includes the topics from the Society of Manufacturing Engineers Body of Knowledge for Certification of Manufacturing Engineering and Technologists and ABET program criteria. Respondents indicated (in their opinion) how well graduates should be prepared in each topic. A secondary benefit of this survey and evaluation is the validation of the topics and structure of the Four Pillars of Manufacturing Knowledge, with the opportunity to contribute to evolutionary improvements.

This paper provides documentation and analysis of manufacturing company priorities for manufacturing topics in engineering or technology programs. Academic programs can benefit by assessing their effectiveness to fulfill the needs and expectations of manufacturing industries, gaining insights for appropriate curriculum revisions to enhance the job-readiness of students to serve these 'customers' of our academic services.

The paper ends with a summary of observations, conclusions, and recommendations for use of the results. Among others, some significant outcomes are:

1. The Four Pillars of Manufacturing Knowledge model is a useful tool for informing a wide set of populations, both industry professionals and educators, about the breadth of the manufacturing field.
2. By identifying respondents with their focus among six different types of academic programs, the survey responses provide insights on the differences in relative importance of the large number of topics that make up the manufacturing field.
3. The survey results show that there are meaningful differences among the variety of types of manufacturing programs and that the Four Pillars model is useful in curriculum planning. While not being prescriptive, the model can help educators tailor their programs to meet the needs of the industries served and the career expectations of their graduates.

The Four Pillars of Manufacturing Knowledge

Foundational for this survey was definition of the various topics that compose the fields of manufacturing. The Society of Manufacturing Engineers (SME) developed the term "Four Pillars of Manufacturing Knowledge", influenced by the conversations conducted by the Manufacturing Education & Research community. The SME Center for Education identified a clear need for a common model of the manufacturing engineering field that could aid in planning the continuous improvement of manufacturing-related curricula of all types, and to help the broader society better understand the wide breadth and deep depth of the field. To this end, the center leaders created the Four Pillars of Manufacturing Knowledge in early 2011. See Figure 1.

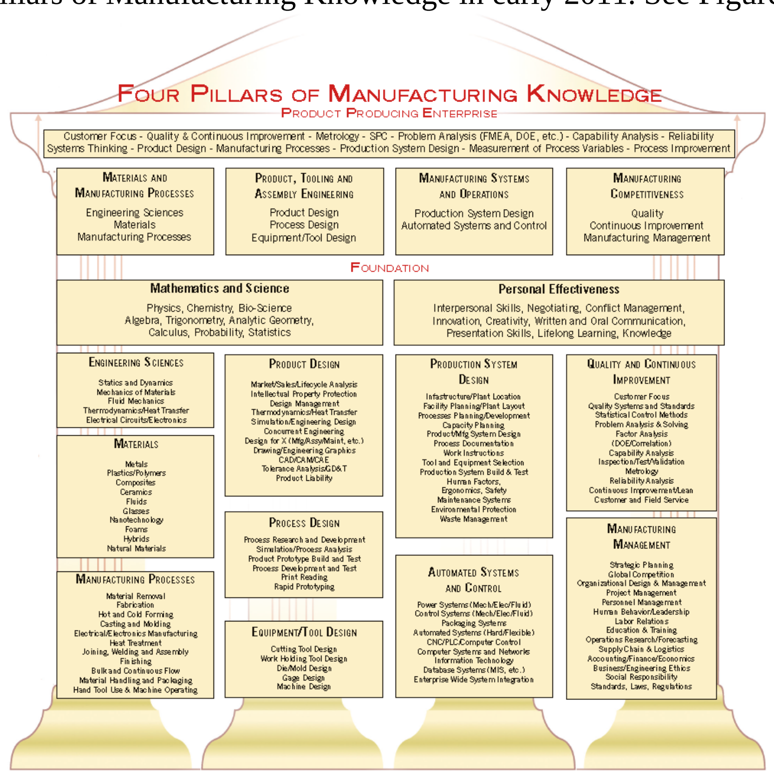


Figure 1. Graphic Representation of the Four Pillars Model.
For a PDF and details of the above go to www.sme.org/fourpillars

The Four Pillars model graphically depicts the topics from the SME document, *Certified Manufacturing Technologist and Certified Manufacturing Engineer – Body of Knowledge*, (SME, 2010) organized under the four categories of program criteria for ABET accreditation of Manufacturing Engineering and Manufacturing Engineering Technology programs (ABET, 2012). These topics were rigorously developed with significant industry input on the skills and knowledge required by manufacturing professionals. First introduced at the June 2011 SME Annual Conference, the model was also a major component of the research on manufacturing educational needs entitled "*Curricula 2015: A Four Year Strategic Plan for Manufacturing Education*." (SME, 2011). The headings in the upper four boxes in Figure 1 identify the Four Pillars.

This model essentially differentiates the unique character of manufacturing, manufacturing engineering, and manufacturing engineering technology, defines the standard for advanced manufacturing topics, and provides a body of knowledge with which all those engaged in advanced manufacturing education can align. It is a tool for promoting greater understanding of the breadth and depth of the field of manufacturing engineering. Initiatives are ongoing, led by the SME Center for Education, to build on this foundation, to promulgate the model broadly within SME, and to engage in dialog with other professional societies that represent engineering, engineering technology, industrial technology, and related educational programs from whose graduates enter manufacturing-related career paths.

A variety of academic programs engage in manufacturing instruction with each having its own emphases, typically targeted to employment in certain segments of manufacturing fields. Examples of those programs that include the term *manufacturing* are Manufacturing Engineering, Manufacturing Engineering Technology, and Industrial Technology-Manufacturing. In addition, some programs are baccalaureate level and some are associate level.

One objective of this survey was to provide input to the decision making by manufacturing educators in these types of programs for manufacturing education. What content and relative emphasis should be placed on the many topics that make up the field of manufacturing?

Survey Instrument

The survey was created in Survey Monkey, and then distributed as an email to a significant number of industry practitioners and educators through SME and ASEE distribution and list serves. An incentive of $100 was offered in a drawing of respondents who completed the survey.

1. Responders were asked for which kinds of academic programs they are primarily responding. Multiple responses were permitted. Six options were provided:
   - Bachelor Degree in Engineering (BS-Engr.)
   - Associate Degree in Engineering Technology (ASET)
   - Bachelor Degree in Engineering Technology (BSET)
   - Associate Degree in Industrial Technology (ASIT)
   - Bachelor Degree in Industrial Technology — Management Track (BSIT-Mgt)
   - Bachelor Degree in Industrial Technology — Technical Track (BSIT-Tech)

2. Survey responders were asked to identify their primary background: Manufacturing management (Industry), Manufacturing engineering (Industry), Manufacturing education (Academia), or Professional or Academic administration. Multiple responses were permitted for those whose careers spanned more than one area to a significant degree.

3. Eleven sets of topics, derived primarily from the Four Pillars model, were then presented and the responders were asked to indicate how well prepared graduates should be on each topic on a five-point Likert scale. The selection options were:

Not Important	Useful	Important	Very Important	Critical
(Not used or N/A)	(Remember)	(Understand or Apply)	(Analyze or Evaluate)	(Create)

   The terms in parentheses were derived from concepts such as the Bloom's Taxonomy to gauge the level at which learners should demonstrate proficiency. During analysis of the data, values of zero to four (0, 1, 2, 3, 4) were used for the five response options. Therefore, the higher numbers indicate higher expectations of proficiency.

   The ten major subject areas shown on the Four Pillars model made up the first ten sets of topics in the survey with each having multiple sub-topics ranging from five to twelve. The 11th area was labeled "Miscellaneous topics" and it included five items that were not specifically mentioned in the Four Pillar model. A total of 99 topics were included in the eleven sets.

4. The final survey item asked each responder to indicate their primary fields of manufacturing experiences, with 20 options provided.

Appendix A. lists the sorted Overall Rankings by Survey Respondents

Appendix B. provides Number and Distribution of Respondents, with Demographics

Appendix C. gives Comments by Survey Respondents to Indicated Questions in the Survey

Analysis of data

A number of subgroups were established for comparison on the 99 topic areas. Positions were also regrouped for comparison of industry verses academics. These groupings include:

- Six Degree programs:
  — BS-Engr. (BS Degree-Engineering)
  — ASET (Associate Degree-Engineering Technology)
  — BSET (BS Degree-Engineering Technology)
  — ASIT (Associate Degree-Industrial Technology)
  — BSIT-Mgt (BS Degree-Industrial Technology — Management Track)
  — BSIT-Tech (BS Degree-Industrial Technology — Technical Track)
- Twenty industry areas of practice.

- Four professional positions:
  — Manufacturing Management (industry practitioners)
  — Manufacturing Engineering (industry practitioners)
  — Manufacturing Education (academia)
  — Academic Administration

One of the more interesting comparisons was the differences in ranking and importance between the positions, and particularly Academic Administrators seemed to have a considerably different opinion than the other groups on numerous topics. Many of these were statistically significant differences.

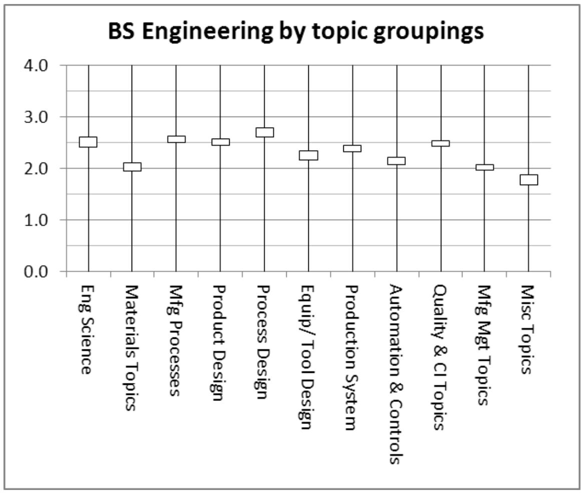
To help correlate the discussion of results with the graphic representation of the Four Pillars model in Figure 1, please note there are ten categories of topics aligned under the four pillars.

1. Pillar 1: Materials and Manufacturing Processes – Three categories
   a. Engineering Sciences
   b. Materials
   c. Manufacturing Processes
2. Pillar 2: Product, Tooling, and Assembly Engineering – Three categories
   a. Product Design
   b. Process Design
   c. Equipment/Tool Design
3. Pillar 3: Manufacturing Systems and Operations – Two categories
   a. Production System Design
   b. Automated Systems and Control
4. Pillar 4: Manufacturing Competitiveness – Two categories
   a. Quality and Continuous Improvement
   b. Manufacturing Management

The following pages display box-and-whisker diagrams of the data. These graphically show max., min., and ranges for each of the ten categories of topics aligned under the four pillars (the boxes in the Four Pillars Model) for each of the degree programs. There were some natural topic area clustering and the patterns for the Industrial Technology (IT) programs seemed to have similar patterns with large clusters, while there was more distinction between the clusters for the Engineering Technology programs and for BS-Engineering as well. It is interesting to note that the topic groupings actually have a clustering effect that is not the same between the various degree programs.

The following Box-and-whisker diagrams presented in this research are not the traditional quartile style. While the vertical whiskers indicate the range of responses low and high ratings and the box is centered about the sample mean, box height has a different basis. The height of the box is the z-score 80 percentile range which is a function of sample standard deviation and sample size and is intended to provide insight into significant differences. This allows one-tailed comparison at 10% in either direction. The actual tests are 90% with 10% error.

BS Degree-Engineering



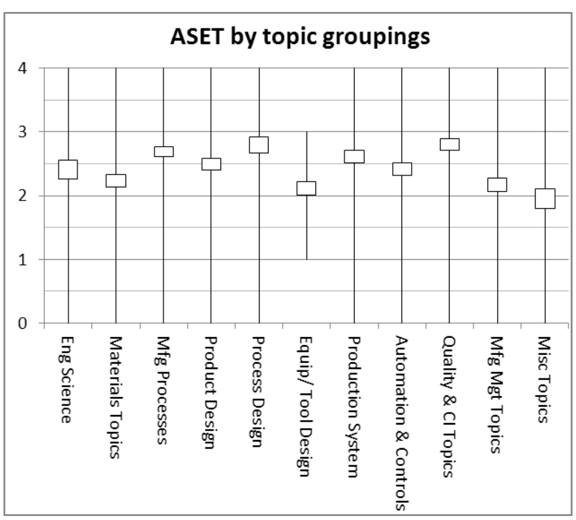
For BS-Engineering, “Process Design” clearly stands out as significantly (p = 2.2%) the highest priority of topic groupings.

The remaining topic groupings are significantly different from all other topic groupings except for one pair that are clustered. “Manufacturing Management” and “Materials” are not significantly different (p = 42.9%)

Another observation is that due to large standard deviations, “Quality & CI (continuous improvement) Topics” are not significantly different from “Product Design” and “Engineering Science” topic groupings when comparing the larger mean and standard deviation to the smaller mean. However, when comparing the smaller mean and standard deviation of the “Quality & CI” to the other two larger mean topic group distributions there is a statistical significance (p = 3.2% & 4.7% respectively).

BS-Engineering showed a central clustering of three topic group areas: “Production System,” “Equip/Tool Design”, and “Automation & Controls” appear to provide a block of topic groups that are quite independent and most statistically significantly different from all other groups. It is quite interesting that “Materials Topics” and “Manufacturing Management Topics” are in a statistical tie (p = 42.9%) for the lowest of the original 10 topic areas, and “Misc. Topics” were clearly and significantly the lowest, alone at 11th (largest p-value comparison of means is 0.3%). As will be explained later, that 11th non-model category is significantly different for all except the two BSIT programs. This lowest rank topic group may provide insight for the BSIT programs.

Associate Degree-Engineering Technology



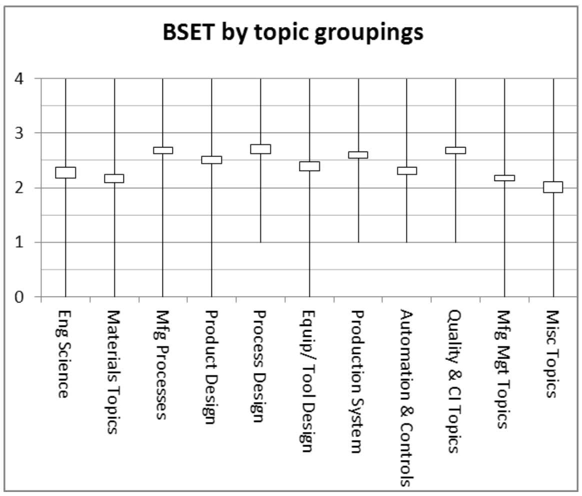
As with most degree programs, topic groupings had a clustering effect in pairs or sets of three or even more. For ASET, “Process Design” is highest, but it is not significantly different from “Quality & CI)” (p = 48.2%). “Mfg Processes” is significantly different from “Quality and CI” (p = 5.7%), but not significantly different from “Process Design” (p = 13.0%)
Similarly, there is no significant difference between “Manufacturing Processes” and “Product System Design” (p = 12.9%)
Thus this first cluster of topic groupings is a significantly different grouping from all other topic groups and clusters.

The second cluster has three topic groups: “Product Design”, “Eng Sciences” & “Automation & Controls” as being not statistically different (p-values range from 12.8% to exactly equal at 50%).

The third grouping is “Materials,” “Mfg Management Topics,” & “Equip/Tool Design,” in that order. Materials and Equipment/Tool Design are significantly different (p=6.5%) but Manufacturing Management, the middle of these three topic groups is not significantly different from the other two (p-values all in the low 20% range)

The “Misc. Topics” were the lowest for all degree programs, and were significantly the lowest for four of the degree programs BS-Eng, ASET, BSET & ASIT.

<u>BS Degree-Engineering Technology</u>

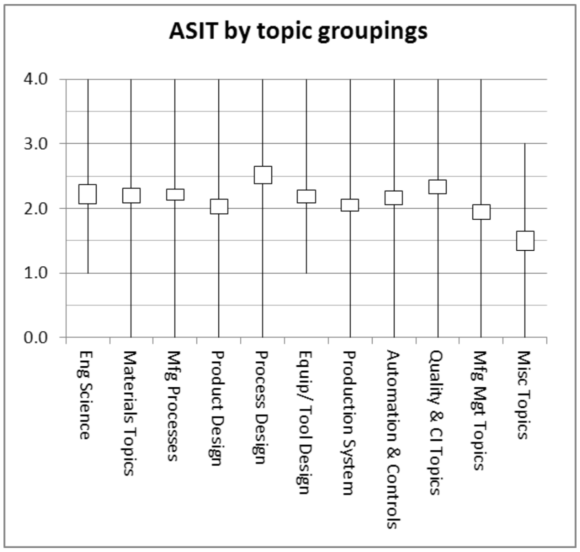


This provided a slightly different order from the previous two degree programs, as well as other degree programs. Notice that the box and whisker chart shows no zeros for four topic areas, even though some were not among the highest ranked topic groups. The absence of a zero score indicates that not even one respondent indicated that any of the topics in these groups was unimportant or not applicable.

There is the same initial cluster, with slightly different order as the ASET degree program but the same initial grouping. This turns out to have three basic topic grouping clusters with no significant differences within the cluster, but significant differences between clusters. Three topic groups were significantly different from all others: “Production System Design” (largest p-value was 3.7%), “Product Design” (largest p-value with any other group was 2.9%) and “Equipment/Tool Design” (significantly different at the 9.8% level with “Automation and Controls”).

The second clustering of topic groups was “Automation and Controls” with “Engineering Sciences” (p- value at 30.9%), but there was a tie between this second and the third cluster. The difference in “Engineering Sciences” and “Manufacturing Management” was not significant (p = 11.3%) when evaluating the mean of “Manufacturing Management” to the distribution of “Engineering Science”. However, when comparing in the opposite direction, the mean of “Engineering Science” to the distribution of “Manufacturing Management” topic grouping there is significant difference (p = 1.3%).

Associate Degree-Industrial Technology



ASIT has less significance between the clusters, and larger number of groups in a central cluster.

This is the only degree program where for the "Misc. Topics" there were no ratings of "4 (critical)", indicating any of the individual topic areas in this group are critical. This is not the case for any other degree program and the rating for this non-model group, Miscellaneous Topics" in the two BSIT degree program types has this topic group in a statistical tie with other topic groups that were in the Four Pillars Model.

The highest rated is the "Process design" topic grouping. This is significantly different from "Quality and CI" (p -= 7.5%).

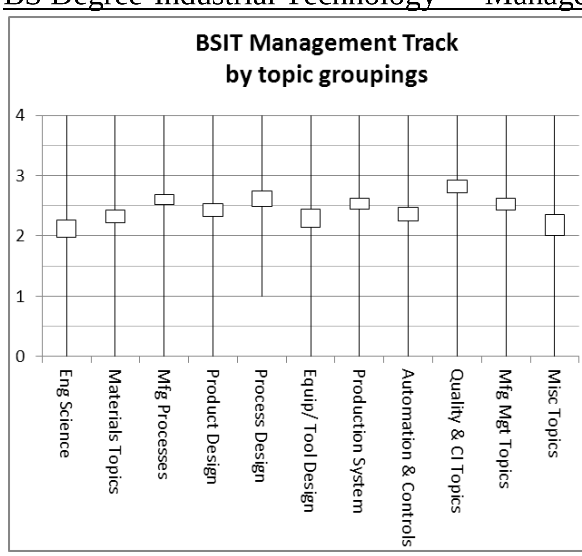
One large cluster of topic groups include those ranked third to seventh in expected proficiency. These include topic groups, in rank order: Equipment/Tool Design, Manufacturing Processes, Materials topics, Engineering Science and Automation and Controls. There is no significant difference in this large central grouping of topic areas (p-values ranged from 22.0% to 49.4%).

The eighth topic group, Production System design, is not significantly different from two of the five in that second cluster, Engineering Science and Automation & Controls (p = 14.2 and 13.2 respectively), and also is not significantly different from the Product Design topic grouping which follows (p = 19.9%).

While the tenth topic, Manufacturing Management topic group is significantly different (p = 4.2%) than Production System Design topic group, it is not significantly different from Product Design (p = 22.3%).

As with all previous topic groupings, the eleventh topic category, Miscellaneous Topics, was significantly different (p = 0.1%) from the next closest average.

BS Degree-Industrial Technology — Management Track



Clearly, the highest rated topic group, Quality and Continuous Improvement is significantly different from all other topic groups (the maximum p-value is 2.6% with Process Design).

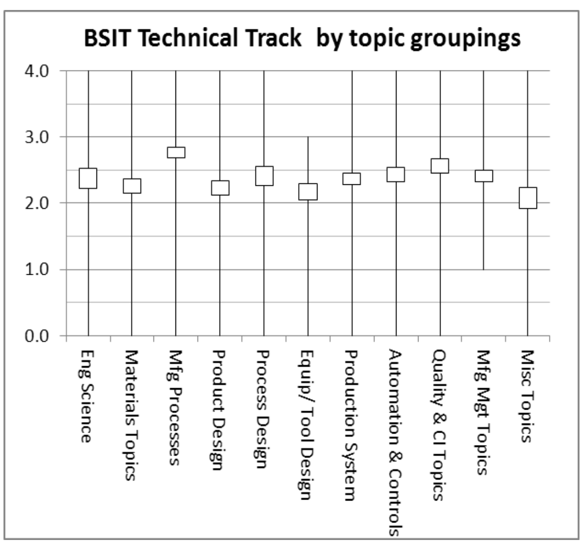
A cluster of topic groups follow that include the second to the fifth. These include, in rank order: Process Design, Manufacturing Processes, Production System Design, and Manufacturing Management. There is one p-value of 9.6% between Manufacturing Management and Manufacturing Processes when tested in that order. However, when testing in the opposite direction, the mean of the latter with the distribution of the former the p-value is 13.5%. For this reason, the difference in proficiency rating averages for these two topic groups are considered to not be statistically significant.

While there appear to be two major but linked clusters of similarly rated topic groups, the division is not as clearly delineated as other degree programs. Perhaps this two-year degree program results represent an increased diversity of offerings and thus expectations as they seek to satisfy their respective but differing constituents.

The second large cluster includes Product Design, Automation & Controls, Materials Topics and Equipment/Tool Design. The only significance was just over a p-value of 5.0% between the Equipment/Tool Design topic group average when compared to the Product design distribution. The opposite comparison where the latter average was compared with the former topic group distribution, however, indicated a p-value of 12.6%. Thus, this is not considered to be a significant difference.

The last two topic groups included Miscellaneous Topics and Engineering Science. There was no significant difference in the ratings for these two. Interestingly the two BSIT degree programs were the only ones where the Miscellaneous Topics grouping was not significantly different from all other topic groupings.

<u>BS Degree-Industrial Technology — Technical Track</u>



For this degree program, the first two topic groupings were significantly different as well as statistically different from all other topic groupings. "Mfg Processes" topic group was clearly the highest rated with "Quality & Continuous Improvement" a distant second.

The remaining topic groups had two basic clusters where differences were not statistically significant. The first cluster includes, in rank order, "Mfg Mgt", "Automation & Controls", "Production System Design", "Process Design" and "Engr Science". Average proficiency ratings for these topic groups were between 2.40 and 2.45 and there is no statistically significant difference between these.

A less defined and separated cluster of topic areas includes "Materials Topics", "Product Design", and "Equipment/Tool Design". The first of these, "Materials", is not significantly different from "Process Design" and "Engineering Science" from the previous cluster (p = 13.1% and 14.7% respectively). Also the lowest rated of the topic groups from the Four Pillars Model, "Equipment/Tool Design" is not significantly different from the "Miscellaneous Topics" group that was added for this study (p = 24.1). "Miscellaneous" topic grouping was also not clearly different from “Product Design”. As before, there are actually two comparisons that are made. A comparison in rank order provides a p-value of 7.6%, but in the opposite direction, the p-value is 15.2%. “Miscellaneous Topics” is significantly different from “Materials Topics” (p = 2.1%).

Thus, the two BSIT degree programs are the only ones where the “Misc Topics” group was not significantly different from all other topic areas represented in the Four Pillars Model.

Additional observations

1. The five-point Likert scale (zero to four) used in the survey was effective in giving respondents opportunities to rate the relative importance of each of the 99 manufacturing-related topics over the range: Not Important (0), Useful (1), Important (2), Very Important (3), and Critical (4).
2. The provision of additional modifiers for each rating level was helpful to relate the ratings to how professionals in the manufacturing workforce from production operators, to technicians, supervisors, engineers, and managers are expected to master each given topic. The modifiers were: (0) – Not used or N/A; (1) – Remember; (2) – Understand-Apply; (3) – Analyze-Evaluate; (4) – Create.
3. The survey results permitted the comparison of responses from several types of professionals from academia, manufacturing management, manufacturing engineering, professional administration, and academic administration.
4. The nature of the survey, its results, and the methodology used to prepare and implement the survey should have broader utility for curriculum planning as an aid to mapping the most desirable elements from among the wide array of topics listed (99) to the mission and objectives of a given type and level of program. Examples include:
    a. Graduates from manufacturing-named associate degree programs should acquire a basic level of knowledge and understanding about the entire breadth of topics that make up the manufacturing engineering field. They should gain more in-depth knowledge and ability to apply materials and manufacturing processes topics, equipment/tool design topics, and quality control topics; and a solid foundation in mathematics, science, communication and other personal effectiveness skills in order to pursue higher degrees and to engage in continuing education on the job.
    b. Graduates from manufacturing-named bachelor level programs would be expected to have mastered a larger number of topics from the Four Pillars of Manufacturing Knowledge to a greater depth than those from associate degree programs
    c. Graduates from bachelor level management-focused industrial technology programs would be expected to place more emphasis on manufacturing processes, process design, quality, continuous improvement, production system operation, and manufacturing management and less emphasis on engineering sciences, materials, product design, equipment/tool design, and automated systems and control.
    d. Graduates from non-manufacturing named programs, who enter manufacturing-related functions of product-producing industries, should have a basic level of knowledge and understanding about the entire breadth of topics that make up the manufacturing engineering field. This will enable them to consider more carefully manufacturability within the product design process, and to participate more effectively on product development teams with other manufacturing professionals.

Extensive statistical analysis was conducted in preparing this paper. Data and details are available to members of SME at the http://i.sme.org/myprofile/profile/ site in the SME library for the Manufacturing Education and Research Community. Information may also be requested by contacting Asst. Professor Carl Williams RE., CMfgE, at crwillia@memphis.edu .

Conclusions and recommendations for use of results

The analysis of survey results has provided insights as to how different types of educational programs can enhance their curricula with regard to manufacturing topics. Respondents included academic professionals from the viewpoints of many kinds of academic programs; engineering, engineering technology, and industrial technology at the bachelor and associate degree levels.

Globally, manufacturing is a common interest. An increasingly important aspect of engineering and technology education is preparation of a technical and engineering workforce capable of working to design and manufacture products on a global basis, for a global market place.

This paper and the model developed using the topics and methodology to test for conclusions are expected to lead to future investigations of the depth of learning on manufacturing topics that education programs should provide. Institutions with degrees, options, minors, and coursework in manufacturing should strive for an understanding of the priorities and preferences of manufacturing knowledge, skills and abilities that will benefit their customers. It should also serve as a model to understand better the extent that concepts about manufacturing and how things are made should be integrated into STEM education programs at all ages and grades.

The SME Body of Knowledge for Certification of Manufacturing Engineers and Technologist topics included in the Four Pillars of Manufacturing Knowledge provides a basis for a common understanding of manufacturing. These topics provide a basis for defining competencies and identifying levels of understanding that students should gain from various education programs.

Valuable insights are gained from this survey data and analysis. The Four Pillars model is validated to the satisfaction of the authors, and the priorities of the sample population are better understood. More significantly, there has been identification of opportunities for refinement and processing of a more extensive and more effectively designed survey to a larger population.

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Appendix A. Overall Rankings by Survey Respondents

A primary objective of this survey was to identify the topics of highest value to manufacturing companies, and also those of significantly lower value. Although it is understood that various institutions and industries will have different priorities, this does offer the opportunity to consider which ones might be appropriate for emphasis. At the same time, those considered less important might be reviewed to see if they represent a disproportionate component of an existing curriculum. If some topics were to be added or expanded, others would probably need to be reduced.

The following table shows the rank-order of the aggregated values for all 107 valid respondents.

Topics in overall rank order
Scoring Rubric:
0 = Not important (or N/A)
1 = Useful (Remember)
2 = Important (Understand/Apply)
3 = Very important (Analyze/Evaluate)
4 = Critical (Create)

Rank	Topic	Mean	Std. Dev.	Count (n)
1	Problem Analysis and Solving	3.061	0.8226	98
2	Fabrication	2.981	0.8084	105
3	Print Reading	2.970	0.9198	99
4	Metals	2.952	0.7768	105
5	Drawing/Engineering Graphics	2.913	0.8978	103
6	CAD/CAM/CAE	2.904	0.8648	104
7	Continuous Improvement/ Lean	2.848	0.9188	99
8	Material Removal	2.838	0.8893	105
9	Tolerance Analysis/GD&T	2.825	0.8451	103
10	Project Management	2.813	0.7856	96
11	Product Prototype Build and Test	2.800	0.8876	100
12	Plastics/ Polymers	2.760	0.8976	104
13	Process Development and Test	2.697	0.8506	99
13	Customer Focus	2.697	1.0542	99
15	Joining, Welding & Assembly	2.676	0.8492	105
16	Design for X (Mfg/Assy/Maint.,etc.)	2.653	0.9320	101
17	Process Documentation	2.650	0.9143	100
18	Tool and Equipment Selection	2.647	0.8634	102
19	Statistical Control Methods	2.646	0.8609	99
20	CNC/PLC/Computer Control	2.643	0.8881	98
21	Hot and Cold Forming	2.635	0.8251	104
22	Human Factors, Ergonomics, Safety	2.634	0.8686	101

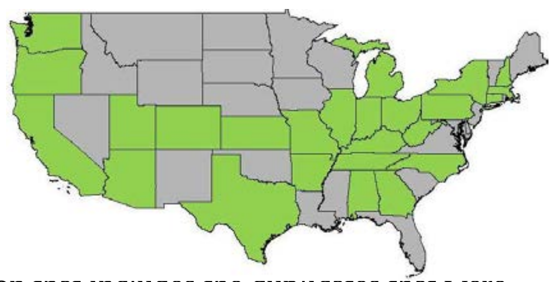
23	Mechanics of Materials	2.619	0.9940	105
24	Work Instructions	2.604	0.8612	101
25	Inspection/Test/Validation	2.592	0.7843	98
26	Casting and Molding	2.585	0.8604	106
27	Composites	2.579	0.9011	107
28	Quality Systems & Standards (incl. ISO/TS)	2.571	0.8495	98
29	Rapid Prototyping/Additive Manuf/3D Printing	2.566	0.9811	99
30	Hand Tool Use & Machine Operating	2.552	0.9092	105
31	Process Planning & Development	2.550	0.9574	100
32	Metrology	2.525	0.8846	99
33	Product Manufacturing System Design	2.525	0.8555	101
34	Concurrent Engineering	2.520	0.9154	100
35	Production System Build and Test	2.500	0.8983	102
35	Control Systems (Mech/Elec/Fluid)	2.500	0.8706	96
37	Heat Treatment	2.495	0.9315	105
38	Finishing	2.490	0.8125	104
39	Business & Engineering Ethics	2.474	1.0089	95
40	Electrical/Electronics Manufacturing	2.472	0.8642	106
41	Capability Analysis	2.439	0.9423	98
42	Electrical Circuits/Electronics	2.425	0.9557	106
43	Simulation for Engineering Design	2.384	0.9970	99
44	Capacity Planning	2.380	0.9404	100
45	Factor Analysis (DOE/Correlation)	2.378	0.8557	98
46	Work Holding Tool Design	2.373	0.9326	102
47	Statics and Dynamics	2.346	1.1215	104
48	Human Behavior/ Leadership	2.344	0.9383	93
49	Design Management	2.333	0.9047	102
49	Automated Systems (Hard/Flexible)	2.333	0.8165	96
51	Reliability Analysis	2.323	0.8551	99
52	Simulation for Process Analysis	2.313	0.8648	99
53	Computer Systems and Networks	2.313	0.9326	96
54	Facility Planning/Plant Layout	2.284	1.0184	102
55	Material Handling & Packaging	2.283	0.8592	106
56	Process Research & Development	2.273	0.9127	99
57	Die/Mold Design	2.262	0.8397	103
58	Power Systems (Mech/Elec/Fluid)	2.258	0.8451	97
59	Maintenance Systems	2.257	0.8325	101
60	Machine Design	2.255	0.9301	102
61	Customer and Field Service	2.224	0.9689	98
62	Environ. Protection/Green/Waste Mgt/Sustainability/ISO14000	2.218	0.9445	101
63	Education and Training	2.211	1.0095	95
64	Standards, Laws, Regulations	2.202	0.9901	94
65	Equipment Cycle-time Optimization	2.179	1.0516	95
65	Time-study / Work Measurement	2.179	0.9451	95
67	Ceramics	2.143	0.9449	105

68	Theory of Constraints concepts	2.141	1.0852	92
69	Cutting Tool Design	2.137	0.8564	102
69	Gage Design	2.137	0.7965	102
71	Product Liability	2.109	0.9263	101
72	Personnel Management	2.108	0.9144	93
73	Information Technology	2.104	0.8763	96
74	Strategic Planning	2.097	1.0007	93
75	Fluid Mechanics	2.088	0.9760	102
76	Bulk and Continuous Flow	2.087	1.0395	103
77	Supply Chain Management & Logistics	2.064	1.0555	94
77	Social Responsibility	2.064	0.9816	94
79	Fluids	2.058	0.8837	103
80	Marketing/Sales/Lifecycle Analysis	2.029	0.9441	103
81	Organizational Design & Management	2.021	0.9614	94
82	Global Competition	2.011	1.0106	94
83	Thermodynamics/Heat Transfer	2.000	0.9600	103
84	Intellectual Property Protection	1.931	1.0701	101
85	Database Systems (MIS, etc.)	1.928	0.8196	97
86	Enterprise Wide Systems Integration	1.927	0.9760	96
87	Nanotechnology	1.903	1.0893	103
88	Accounting/Finance/Economics	1.883	0.9023	94
89	Packaging Systems	1.865	0.8159	96
90	Operation Research/ Forecasting	1.862	0.8872	94
91	Natural Materials	1.837	0.9564	104
92	Infrastructure/Plant Location	1.822	0.9838	101
93	Labor Relations	1.789	0.9664	95
94	Thermodynamics/Heat Transfer	1.782	0.9445	101
95	Glasses	1.767	0.8879	103
96	Hybrids	1.712	1.0017	104
97	Foams	1.549	0.8160	102
98	Auto ID Technologies/ Radio Frequency ID	1.532	0.8257	94
99	Can speak any foreign language	1.463	0.9655	95

Appendix B. Number and Distribution of Respondents, with Demographics

- 129 total responses, 107 were considered valid, useful, and were used in analysis.
- Of the 107 responses that were used in the analysis:
    - Many had partial answers or incomplete surveys, even on demographic categories. The absence of an answer was NOT considered the same as a zero.
    - Multiple responses were accepted and even encouraged for demographic type information such as professional position, degree program and industry area.
    - Nine did not cite a position, but are included in the respondent analysis figures. There was no special category of those who did not indicate a professional position.
    - Seven did not indicate a degree program; however, this was added as a degree program option—"No program Specified."
    - Nineteen of the 107 responses did not indicate an industry area of experience, while others selected multiple responses as was encouraged. Most selected one or two of the 20 categories,
    - The vast majority (91 of 107) answered most all of the 99 topic questions.
- Figures, calculations and analysis include only the 107 responses considered valid.
- Respondents locations of those providing info. (25 states, one from Canada; 36 did not provide location info):

AL	AR	AZ	CA	CO
CT	GA	IL	IN	KS
KY	MA	MI	MO	NC
NH	NY	OH	OR	PA
TN	TX	UT	WA	WV



General summary of data used for program evaluation that includes the duplicates that were allowed. Some responses indicated multiple programs and/or more than one position and have duplicated records.

- 111 industry (Manufacturing Management or Manufacturing Engineer)
- 82 educator (Manufacturing Educator or Academic Administration)
- 113 Engineering Technology (ASET & BSET)
- 108 Industrial Technology (ASIT, BSIT-Mgt Track, BSIT- Tech Track)
- 35 Engineering (BS-Engr.)

Appendix C. Comments by Survey Respondents to Indicated Questions

- How prepared should graduates be in these Engineering Sciences?
  - Nanotechnology is Very Important, as is Composites, but not in a day to day league with metal yet and should not be over emphasized. as such.
  - (Add) material forms like powders, granules, etc.
- How prepared should graduates be in these Manufacturing Processes?
  - Add additive technologies - critical
  - (Add) injection mold making, Tool making, tool and die design for manufacturing options understanding during the design phase area needed.
  - (Add) Direct-digital manufacturing (rapid prototyping)
- How prepared should graduates be in these Product Design topics?
  - All core disciplines for the Mechanical Engineer at a company. Engineering Grads and interns have been very weak in CAD drawings preparation, one of the only skills that can be used on Day 1. Need more emphasis on this. The Engineering Drawing controls 100% of the engineering project, worldwide, any language.
  - I believe a level of safety training needs to be in here. Not just a glanced over version
  - (Add) Lean Mfg
- How prepared should graduates be in these Process Design topics?
  - (Add) Print Reading and Creating.
- How prepared should graduates be in these Equipment/Tool Design topics?
  - Depends on type of engineer
- How prepared should graduates be in these Production System Design topics?
  - Safety is first priority.
- General comments
  - (T)hese are all dependent upon the individual's job responsibilities.