Industry Expectations of New Engineers – A Survey to Assist Curriculum Designers

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Abstract

The ABET Criteria 2000 approach creates opportunities for universities to work closely with their key constituencies; such as industry, state regulatory agencies, parents, and students to define general and specific goals and objectives for their university - unique education programs. For example, while Criteria 2000 lists eleven student educational outcome categories, it requires each accredited institution to design its own curriculum based on its own set of outcomes objectives.

Very often surveys, such as those which attempt to capture and quantify industry expectations of the attributes (i.e., skills, knowledge, and experience) for entry level engineering employees, can provide key data useful for determining objectives and helpful in designing curricula to meet the objectives.

This paper outlines the content and results of a survey completed by fifteen companies which used 172 examples of attributes related to the eleven ABET outcome categories to gain data on the perceived importance of the attributes. The survey, current database, and some preliminary analyses are available in hard copy or electronic form. This "first" survey and dataset resulted from efforts of the Industry-University-Government Roundtable for Enhancing Engineering Education (IUGREEE) to initiate a continuing and evolving process to provide curriculum designers with important information from industry.

Introduction

The ABET Criteria 2000 approach used to accredit engineering education curricula creates opportunities for universities to redesign their curriculum but it requires a focus on achieving specific goals, objectives and outcomes. Among them is a list of eleven outcomes that engineering programs must demonstrate their graduates possess upon graduation. The student education outcomes described in the Criterion 3 section of the ABET Criteria 2000 are:

(a) an ability to apply knowledge of mathematics, science, and engineering
(b) an ability to design and conduct experiments, as well as to analyze and interpret data
(c) an ability to design a system, component, or process to meet desired needs
(d) an ability to function on multi-disciplinary teams
(e) an ability to identify, formulate, and solve engineering problems
(f) an understanding of professional and ethical responsibility
(g) an ability to communicate effectively
(h) the broad education necessary to understand the impact of engineering solutions in a global and societal context

(i) a recognition of the need for, and an ability to engage in life-long learning
(j) a knowledge of contemporary issues
(k) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

Each accredited institution is free to specify its objectives in these areas, free to design educational experiences to achieve them, but then must demonstrate a process to measure results and show that outcomes are being achieved. A key requirement in the "curriculum design process"; therefore, is a first step to define the institution's outcomes objectives.

That "outcomes definition" process should involve participation by key constituencies chosen by the university. Very often they would include faculty, parents, students, and potential industry or government employers of the graduates. State regulations may also play a strong role in determining outcomes requirements. Very often in that process surveys, such as those which attempt to capture and quantify industry expectations, can be very useful.

Survey data, which deals with specific skills, attributes, and experiences for entry-level engineering employees, i.e., B.S. degree holders, can be very important. Such data would be especially helpful if it went into depth beyond the level of the eleven ABET outcomes descriptions.

A first attempt at such a survey was initiated by the Industry-University-Government Roundtable for Enhancing Engineering Education (IUGREEE) and the results are now available. They are the prime subject of this paper. Additional information on IUGREEE, its purpose, and activities can be found, for example, in Reference 1.

Survey Questionnaire

That SURVEY contained a listing of 172 skills, knowledge descriptors, and experiences that were grouped into the eleven ABET outcomes categories. The respondents were asked to rank each in importance for an entry-level engineer on a scale of 1 (corresponding to very low) to 5 (corresponding to very high). The survey also asked for importance rankings of the same topics for engineers with 3 to 5 years of experience. An example page from the survey is shown in Figure 1 where some of the 18 topics in the "ability to design a system, component, or process" category are shown. The checkmarks are used to show an example response.

Note from the example a general survey result that all items were ranked more important for experienced engineers than entry-level engineers. The implication then is that continuing education, from some source, is expected beyond the entry level. While all survey data is available for further analysis, this paper will focus on the results only for entry-level engineers.

Survey Results

To date, 420 engineers and engineering managers, representing fifteen companies, have completed the survey. Each respondent was asked to identify his or her current position, team experience, job specialization and engineering discipline background by checking applicable items from a supplemental questionnaire shown in Figure 2.

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(c) Ability to design a system, component, or process to meet desired needs

Knowledge/Experience	Experience Level	Level of Importance (Low) 1	2	3	4	5 (High)
3.1 Understanding of the concept and meaning of "form follows function"	New Graduate			√		
	3-5 Years After Graduation				√	
3.2 Knowledge and understanding of (aerospace and defense) product life cycle	New Graduate		√			
	3-5 Years After Graduation				√	
3.3 Knowledge and understanding of (aerospace and defense) product design and development cycle	New Graduate			√		
	3-5 Years After Graduation				√	
3.4 Knowledge of the performance, environment and design criteria for typical aerospace and defense products	New Graduate		√			
	3-5 Years After Graduation				√	
3.5 Knowledge of the operations, support, and maintenance requirements of aerospace and defense products	New Graduate		√			
	3-5 Years After Graduation				√	
3.6 Knowledge and understanding of DFMA	New Graduate		√			
	3-5 Years After Graduation			√		
3.7 Knowledge and understanding of "the concept of robustness"	New Graduate			√		
	3-5 Years After Graduation				√	
3.8 Knowledge of materials and processes associated with aerospace and defense products						
3.8.1 Materials and materials science	New Graduate			√		
	3-5 Years After Graduation				√	
3.8.2 Unit manufacturing processes	New Graduate		√			
	3-5 Years After Graduation			√		
3.8.3 Work flow and assembly processes	New Graduate		√			
	3-5 Years After Graduation				√	

Figure 1 Example Completed Page from the Survey

Experience and Present Responsibilities of the Questionnaire Respondent

Before returning the attached questionnaire, please answer the following questions

MANAGEMENT

- ☐ Yes ☐ No
  - ☐ Program or Project Management
  - ☐ Product Development
  - ☐ Functional/Specialty Department

INVOLVED IN HIRING NEW GRADUATES & PERFORMANCE EVALUATIONS

- ☐ Yes ☐ No

TEAM EXPERIENCE

- ☐ Significant Team Participation
- ☐ Team Leader

EXPERIENCE/TECHNICAL SKILLS (Check the boxes which best fit your experience in Columns A or B)

Column A

- ☐ Structural Design
- ☐ Structural Analysis
- ☐ Mechanical System Design/Development
- ☐ Propulsion
- ☐ Aerodynamics
- ☐ Controls Design/Development
- ☐ Electrical Design/Development
- ☐ Electronic Design/Development
- ☐ Avionics Systems Design
- ☐ Software Development
- ☐ Computer Systems Design/Development
- ☐ Product Support
- ☐ Instrumentation
- ☐ Other: ____________________

Column B

- ☐ Aeronautical or Aerospace Engineering
- ☐ Civil Engineering
- ☐ Computer (Science) Engineering
- ☐ Electrical Engineering
- ☐ Industrial Engineering
- ☐ Mechanical Engineering
- ☐ Manufacturing Engineering
- ☐ Other: ____________________

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Figure 2 Respondent Characteristics

The overall response to the page shown in Figure 2 is shown below in Table 1.

Table 1 Summary of Respondent Characteristics

	Count of Responses
MANAGEMENT	
Management	279
Program or Project Management	78
Product Development	110
Functional/Specialty Department	143
Hiring New Grads/Perf Eval	300
TEAM EXPERIENCE	
Significant Team Participation	260
Team Leader	250
EXPERIENCE/TECHNICAL SKILLS	
Structural Design	107
Structural Analysis	76
Mechanical System Design/Development	98
Propulsion	51
Aerodynamics	50
Controls Design/Development	39
Electrical Design/Development	38
Electronic Design/Development	55
Avionics Systems Design	40
Software Development	80
Computer Systems Design/Development	36
Product Support	65
Instrumentation	28
Other	120
Aeronautical or Aerospace Engineering	114
Civil Engineering	13
Computer (Science) Engineering	26
Electrical Engineering	63
Industrial Engineering	8
Mechanical Engineering	123
Manufacturing Engineering	41
Unknown (Did Not Complete Cover Sheet Questions)	23

Note that a broad and varied range of backgrounds is evident from Table 1 results.

The survey results are formatted to show for each survey item:

a. The count of responses
b. The average importance ranking
c. The standard deviation
d. The maximum, minimum, and maximum-minus-minimum importance levels
e. The median and mode importance levels
f. The total numbers scored for each importance level

An example result corresponding to all 420 respondents' inputs on the Figure 1 questions is shown in Table 2.

Table 2 Database Example

	Questions	Experience Level	Count of Responses	Average	Standard Deviation (Entire Population)	Max	Min	Max minus Min	Median	Mode	#1's	#2's	#3's	#4's	#5's	#6's
3	**Ability to design a system, component, or process to meet desired needs.**															
3.1A	Understanding of the concept and meaning of "form follows function."	*New Graduate*	399	3.0	1.0	5	1	4	3	3	30	77	184	79	27	0
3.1B	Understanding of the concept and meaning of "form follows function."	*3-5 Yrs After Graduation*	395	3.9	1.0	5	1	4	4	4	15	20	72	163	122	0
3.2A	Knowledge and understanding of (aerospace and defense) product life cycle.	*New Graduate*	409	2.4	1.0	5	1	4	2	2	77	146	136	39	9	0
3.2B	Knowledge and understanding of (aerospace and defense) product life cycle.	*3-5 Yrs After Graduation*	404	3.8	1.0	5	1	4	4	4	16	27	87	172	99	0
3.3A	Knowledge and understanding of (aerospace and defense) product design and development cycle.	*New Graduate*	410	2.5	1.0	5	1	4	3	3	79	124	137	63	5	0
3.3B	Knowledge and understanding of (aerospace and defense) product design and development cycle.	*3-5 Yrs After Graduation*	405	4.0	1.0	5	1	4	4	4	14	17	70	166	135	0
3.4A	Knowledge of the performance, environment, and design criteria for typical aerospace and defense products.	*New Graduate*	408	2.5	1.0	5	1	4	2	3	83	127	129	62	6	0
3.4B	Knowledge of the performance, environment, and design criteria for typical aerospace and defense products.	*3-5 Yrs After Graduation*	403	4.0	1.0	5	1	4	4	4	16	17	69	166	132	0
3.5A	Knowledge of the operations, support, and maintenance requirements of aerospace and defense products.	*New Graduate*	407	2.1	1.0	5	1	4	2	2	129	130	116	29	2	0
3.5B	Knowledge of the operations, support, and maintenance requirements of aerospace and defense products.	*3-5 Yrs After Graduation*	401	3.6	1.1	5	1	4	4	4	20	33	112	151	82	0
3.6A	Knowledge and understanding of DFMA.	*New Graduate*	373	2.5	1.0	5	1	4	3	3	79	99	141	42	10	0
3.6B	Knowledge and understanding of DFMA.	*3-5 Yrs After Graduation*	368	3.6	1.1	5	1	4	4	4	23	33	92	128	89	0
3.7A	Knowledge and understanding of "the concept of robustness."	*New Graduate*	404	2.9	1.0	5	1	4	3	3	41	99	156	87	18	0
3.7B	Knowledge and understanding of "the concept of robustness."	*3-5 Yrs After Graduation*	400	3.9	1.0	5	1	4	4	5	7	23	96	135	136	0
3.8	Knowledge of materials and processes associated with aerospace and defense products.															
3.8.1A	Materials and materials science.	*New Graduate*	404	2.8	1.0	5	1	4	3	3	47	109	150	77	19	0

Respondent results can be sorted by any of the Figure 2 categories. For example, results from respondents with mechanical engineering backgrounds can be sorted from the database and their results analyzed separately. Similarly, a sort can be made on aerospace engineers or structural designers, or program managers.

Preliminary Analysis of Survey Results

One use of the survey database is to use the importance rankings to form an overall ranking of the 172 survey skills, knowledge, and experience items within the eleven ABET outcomes categories. In doing this we can see which items are more important than others to achieve in an undergraduate curriculum. For example, an overall ranking for items under the "ability to design a system, component, or process to meet desired needs" outcome yields the list shown in Figure 3.

Note that circled numbers on the left are used to reflect the importance scale. Also note that this list does not include 8 of the 18 items because it was decided not to include items where the largest number of respondents ranked the items either 1 or 2 (i.e. low in importance). A preliminary analysis based on these types of results may conclude:

- Design skills for components, subsystems, processes, then systems are important (in that order).
- An upper-division, team-based (capstone) design course is important.
- Understanding concepts of "form follows function" and "robustness" are important.
- Items below the 3.0 level are less than a medium level of importance.

(c) Ability to Design a System, Component, or Process to Meet Desired Needs

3.4 →
- **Demonstrated Ability to Design a Component**
- **Demonstrated Ability in an Upper-Division, Team-Based Design Project**
- **Understanding of the Concept of "Form Follows Function"**
- 3.0 → **Demonstrated Ability to Design a Subsystem (or Black Box)**
- **Demonstrated Ability to Design a Process**
- **Knowledge and Understanding of "the Concept of Robustness"**
- **Demonstrated Ability to Design a System**
- **Knowledge of Materials and Materials Science**
- **Experience in Designing Systems Considering Performance Requirements**
- **Experience in the Design of Structures Considering Manufacturing and Cost Requirements**

2.6 →

Plus 8 Others

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Figure 3 Importance Rank Order Example

Such conclusions based on analysis can be useful in designing a curriculum to achieve outcomes objectives. Each curriculum designer, however, must determine the amount of skills, etc., which are needed in his/her university. That is, what is the acceptable level to achieve objectives? Also, some items low on the list (or truncated from it) may need curriculum content for other reasons.

One very important caveat in all this is that the limitations of survey data must be well understood. In analyzing responses on the "design" items as compared to all of the ten other areas, there appeared to be consistently lower ratings for the importance of all design items. The average ratings covered the range of 1.7 to 3.3 for the eighteen design items, whereas the ten other categories ranged from 1.7 to 2.6 for the lowest items up to 3.3 to 4.6 for the highest. One reason for this may be that the total pool of respondents was weighted about equally between those with analytical responsibilities and those with design (synthesis) responsibilities. Thus, the data may reflect lack of understanding of and appreciation for design-oriented skills by about half the respondents.

When a sort was done on aerospace and aeronautical engineering respondents (numbering 114 of the 420 respondents), there was a strong consistency in the relative order of importance for all 172 items compared to the overall averages. Only nine items (of the 172) were moved to a different relative ranking. One moved three positions, four moved two and four moved one. The "design items" were ranked the same with no exceptions.

The top three items found for each of the eleven categories from the total database are shown in Table 3. One should therefore, expect to find outcomes objectives in most engineering curricula that deal with these skills, knowledge, and experiences because of their relative and absolute levels of importance. All 33 items are above a 3.0 level of importance and 21 are above a 3.7 level.

Table 3 Top Three Items for Each Category

(a) Ability to Apply Knowledge of Mathematics, Science, and Engineering
- Engineering Courses with Applications (2.5 years)
- Ability to Structure, Solve, and Report on solutions in the Engineering Specialty
- Ability to Apply Knowledge of General Physics (1.5 years)

(b) Ability to Design and Conduct Experiments, as well as to Analyze and Interpret Data
- Demonstrated Ability in Data Analysis and Interpretation
- Team Experience as a Team Member
- Experience in Executing Designed Experiments (1.5 years)

(c) Ability to Design a System, Component, or Process to Meet Desired Needs
- Demonstrated Ability to Design a Component
- Demonstrated Ability in an Upper-Division, Team-Based Design Project
- Understanding of the Concept of "Form Follows Function"

(d) Ability to Function on Multi-Disciplinary Teams
- Function on a Team in Laboratory Science or Engineering courses
- Function on a Team in an Upper-Division, Team Based Design Project
- Function in a Team in Team–Based Reporting of Project Results

(e) Ability to Identify, Formulate, and Solve Engineering Problems
- Ability to Formulate a Range of Alternative Problem Solutions
- Ability to Identify Problems
- Ability to Choose Problem Solution

(f) Understanding of Professional and Ethical Responsibility
- Demonstrated Understanding of the Importance of "Honesty" in Science and Engineering
- Demonstrated Understanding of the Importance of "Code of Ethics" in Engineering Specialty
- Personal Commitment to a Stated or Documented "Code of Ethics"

(g) Ability to Communicate Effectively
- Interpersonal Skills (verbal, non-verbal, and written) which Maintain High Professional Quality, Convey Appropriate Respect for Individuals, Groups, Teams, and Develop a Productive Working Environment
- Ability to Give a "Solo" Presentation
- Ability to Write a Concise Business Letter

(h) Broad Education Necessary to Understand the Impact of Engineering Solutions in a Global/Societal Context
- Understanding that Engineering Solutions are Affected by and should be Responsible to Limited Resource Availability
- Understanding that Engineering Solutions Impact the Environment (e.g. CFCs, Heavy Metals, Energy Consumption, etc.)
- Understanding that Engineering Solutions alter the Structure of Society (e.g. Air Transportation)

(i) Recognition of the Need For, and an Ability to Engage in Life-Long Learning
- Understanding that Skill Training is an Employee's Responsibility and a Part of Life Long Learning

- Plans and Commitments to Skill Improvement in Learning Associated with the Work Environment
- Understanding that Life-Long Education is a Professional Responsibility

(j) Knowledge of Contemporary Issues
- Demonstrated Understanding that Engineering is Affected by Information Technology Issues
- Understanding of the Information Superhighway
- Demonstrated Understanding that Engineering is Affected by Environmental Issues

(k) Ability to Use the Techniques, Skills, and Modern Engineering Tools Necessary for Engineering Practice
- Computer Literacy in Analysis Tools used in Engineering Specialty
- Computer Literacy in Design Tools used in Engineering Specialty
- Computer Literacy in Simulation and Modeling Tools used in Engineering Specialty

<u>Recommended Use and Expansion of the Survey</u>

We recommend careful attention to the survey data in order to understand its strengths and weaknesses in conveying "industry's expectations" of the eleven ABET outcomes categories.

A mechanical engineering department should be interested in the difference in results between mechanical engineering respondents and the overall set. What do large differences mean? What about small differences? Is there ambiguity in the "design" results? Are there other significant differences? When sorting on "design relevant" backgrounds, is it clear how to structure a curriculum to achieve the items?

Questions such as these, can not only lead to best use of the existing data, but can help the IUGREEE and others improve the survey to provide more and better "curriculum design relevant" data. Similar help can come when the database is expanded to include more respondents. For example, the small sample size of respondents with civil engineering experience limits the statistical significance of that data used in isolation to derive requirements for CE curricula.

<u>Capability of the Data Base Utilities</u>

An Excel Data Base, (Release <u>Version 5.0</u>) was created to allow a very large number of responses to be recorded without exceeding the system limits. Up to 16,000 individual responses can be incorporated in the data base. The structure of the data base was established to allow extraction of responses related to aeronautical, mechanical or electrical engineering specialties, etc. These were identified by the respondents with appropriate entries in Column B of Figure 2. In addition, the respondent could identify his technical job description. These were delineated in Column A of Figure 2. The standard mechanisms of the Excel tools can be used to extract responses, which may be applicable to Column A or B responses.

Distribution of the Survey

Electronic or paper copies of the SURVEY can be obtained via e-mail – francis.d.mcvey@boeing.com or by writing to:

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Summary and Conclusions

The first survey of fifteen companies conducted by the Industry-University-Government Roundtable for Enhancing Engineering Education (IUGREEE) has been conducted, and the results are available for use by "curriculum designers." The SURVEY involved "importance ratings" for 172 skills, knowledge elements, and experiences that can be expected by engineering managers and engineers for B.S. entry-level engineers.

The 172 items, when ranked, give an indication of what should be sought as curriculum objectives and in what priority. University "curriculum designers" can sort the data to analyze by engineering academic background or job category. Careful attention must be given to understand the data and its limitations.

This SURVEY provides an example of what can be obtained from industry in order to better understand their outcomes expectations for entry-level engineers. This survey goes beyond that to also include expectations for engineers with 3 to 5 years of experience, thus it can be used to design continuing education, on-the-job training, or M.S. level outcomes objectives.

The survey results can be obtained in hard copy by contacting:

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or in electronic form by contacting Frank McVey's e-mail address – francis.d.mcvey@boeing.com.

Reference

1. Bowman, D.; Lang, J.; McMasters, J. "The Roundtable for Enhancing Engineering Education-an Update," AIAA Paper No. 97-0844, January 1997.

Biographies

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