Engineering Design Education: Surveys of Demand and Supply

Rudolph J. Eggert
Boise State University

Abstract

Two surveys were conducted in 2002 to learn more about the demand and supply of specific engineering design topics and activities, resulting in 1006 industry respondents and 182 academic respondents.

Academia appears to be meeting industry's demand for Engineering Design Specifications, Teamwork and Overall Design Process topics. However, there appears to be a supply gap in academia's current coverage of Creativity Methods, Project management, Design for Manufacture, Design for Assembly, and Product Testing. Industry has a higher demand for Individual Design Projects and Interdisciplinary Design Project activities, in relation to Academia's current coverage. Also, academia appears to overemphasize oral and written design report activities.

A majority of respondents indicated that 25% or less of the department's faculty participates in planning, monitoring and coordinating the design stem. And lastly, personal computers are the preferred choice of CAD platform in industry and academia as compared to Unix stations.

Introduction

Developing an engineering design curriculum to meet the needs of industry for higher quality products is quite a challenge for any institution. When preparing revisions to its curriculum, a department faculty will consider input from a variety of sources including Senior Design Project mentors/sponsors, recent graduates, and industry advisory council members. The advice provides focus and helps to fine-tune the curriculum. Oftentimes, industry asks academia for more than it has the resources to deliver. Contrary to this apparent increased "demand" for more education is the trend by university administrators to downsize the 4-yr degree to about 128 semester credit hours, thereby decreasing the available time to "supply" the education desired.

Four major issues arise in the development of the design stem. What design topics (principles, methods, theories etc.) should be taught? When, in the typical four-year program, should they be taught? How (pedagogical methods) should they be taught? And lastly, how should we measure the outcomes. These issues are not new. Participants of the 1996 NSF Strategic Planning Workshop (NSF [1]) concluded that the three most important design education needs were:

1. Create teachable principles of design process, methods, and tools.
2. Devise innovative pedagogical methods for engineering design, and
3. Measure effectiveness, correctness, and relevance of teaching methods.

Since then a number of initiatives were completed including the NSF sponsored ECSEL program that focused mostly on freshman coursework. Other efforts have been undertaken to include product realization and refinement of major design projects into the design curriculum (Bannerot[2], Doepker[3]). Others aim at integrating design across the curriculum (LeMaster[4], Eggert[5,] Eggert[6]). And lastly, a significant research effort has been undertaken to address design assessment processes through the Transferable Integrated Design Engineering Education project (Davis[7]). However, very little has been reported about the specific design topics or activities desired by industry and or those supplied by academia.

To address the need for specificity, 25,000 industry engineers and 400 institutions were invited to complete a web-based survey during the winter of 2002. The objective of the surveys was to learn more about the demand and supply for specific engineering design topics and activities, specifically:

1. What topics and activities does industry consider important?
2. What specific engineering design topics were being taught?
3. Which years were they being taught (i.e. freshman, sophomore, junior, senior) and
4. What engineering design activities were students participating in, and when?

Why survey industry?

In 2000, the United States Bureau of Labor Statistics reported that 1,465,000 engineers were employed. As shown in Table 1, approximately 50 percent of all engineers worked in manufacturing companies, 27 percent worked in engineering services, 12 percent for government, and three percent self-employed. Approximately eight percent were classified as others.

Table 1. Engineering employment (U. S. Bureau of Labor Statistics[8]).

	Employment	
Employer	**Thousands**	**%**
Manufacturing	732	50
Engineering Services	401	27
Government	179	12
Self-employed	43	3
Other	110	8
Total	1465	100

Manufacturing, which accounts for one out of every two engineering jobs, includes establishments in: Aerospace Manufacturing, Apparel and Other Textile Products, Chemicals Manufacturing/Except Drugs, Drug Manufacturing, Electronic Equipment Manufacturing, Food Processing, Motor Vehicle and Equipment Manufacturing, Printing and Publishing, Steel Manufacturing, and Textile Mill Products.

Engineering services accounts for approximately one out of four engineering jobs. Engineering services refers to companies such as Architect and Engineering companies that design and construct commercial, municipal, and the industrial facilities.

Government accounts for approximately one out of 10 engineering jobs and includes positions in federal, state and local governments.

Therefore, even if engineers are not working directly for a manufacturing business they will most likely be working for a supplier or a customer. If academia wants to educate engineering students for jobs in industry, our curricula must be tuned to industry needs.

Surveys for industry and academe

To expedite the distribution of the surveys and collection of the data, a web-based industry survey was designed and tested in the fall of 2001. A sample industry questionnaire is available for downloading at: http://coen.boisestate.edu/REGGERT/ under the Design Survey Results hotlink. The survey was developed using Microsoft FrontPage 2000 and its "form" feature. The survey was tested on university PC's running Windows NT4 and Windows 2000, running Internet Explorer and Netscape browsers.

Emails were sent to approximately 25,000 engineers working mostly in the US, belonging to ASME's Design Engineering Division and the Manufacturing Engineering Division. Each email invited the recipient to connect to the questionnaire website and answer about 45 quick questions, taking a total of about 10 to 15 minutes. The answers were automatically appended to a secure spreadsheet located at the same website as the questionnaire.

Industry respondents were asked to checkmark topics and activities, listed in table 2, as Very Important, Important or Not Important (default radio button). The topics and activities were carefully selected to be representative of those offered in typical B.S.M.E. degree programs. To keep the survey brief, the topics and activities were listed without explanation or definition. Also, respondents were asked to successively reduce very important topics/activities down to the most important topic/activity. And lastly they selected which CAD platform was more important PC, Unix or other. An open-ended comments box was provided, too.

A parallel academic survey was prepared and included the same topics and activities. Invitations to complete the academic surveys were emailed to members of ASEE's Design Education division, and ASME's Design Engineering Division, Manufacturing division, the Design Automation committee, the NSF-sponsored Decision-Based Design workshop members, and members of the Canadian Design Engineering Network. A number of respondents using Windows95 and Windows ME reported browser problems with the pull-down menus. An alternate, radio-button form was then developed to replace the pull-down menu version.

Recognizing that many topics or activities are reinforced in subsequent courses in subsequent years, faculty were asked to identify all the years in which a topic or activity was taught (i.e. freshman, sophomore, junior and or senior). Other questions pertained to highest degree offered at the institution, the CAD platform most used, and the level of faculty participation in design curriculum planning, monitoring and coordinating.

Discussion of survey results

Who Responded
Industry respondents submitted 1006 useable surveys and academic respondents submitted 182 useable surveys. The industry surveys were completed by individuals listing job titles including: engineer, engineering manager, supervisor, project engineer, Vice President, and President. The

companies read like a list of Standard & Poor's 500 or the Dow Jones 50 industrials. While there are a lot more engineers working in industry than were sampled by the survey, most of the industry respondents were supervisors and or managers, and are instrumental in making hiring decisions.

Table 2. Topics and activities surveyed in both questionnaires.

Q	Topics	Q	Activities
1	Benchmarking of	25	Open-ended problem
2	QFD/House of Quality	26	Creativity exercises
3	Engineering design	27	Reverse engineering
4	Function decomposition	28	Product dissection
5	Function structure	29	House of Quality
6	Reverse engineering	30	CAD-2D
7	Creativity methods	31	CAD-Solid Modeling
8	Literature / web searching	32	Industry based design
9	Design for assembly	33	Interdisciplinary design
10	Design for manufacture	34	Team design project(s)
11	Pugh's method	35	Individual design project(s)
12	Weighted rating method	36	Design report(s) - Oral
13	Solid modeling	37	Design report(s) – Written
14	Rapid prototyping	38	Physical prototype
15	Math. modeling & analysis		
16	Optimization methods		
17	Tolerancing		
18	Product testing		
19	Overall design process		
20	Patents, copyrights,		
21	Engineering economics		
22	Project management		
23	Product marketing		
24	Teamwork		

Academic institutions were widely represented with big schools, small schools, private and public. Of the 182 respondents, 133 (73%) were from U.S. institutions, 49 (27%) were from institutions outside the United States. Sixteen were from Canada (9%) and the remaining were from places such as Australia, Brazil, Germany, India, Italy, Mexico, New Zealand, Nigeria, Singapore and Turkey. Mechanical Engineering departments accounted for 158 (87%) of the respondents. The balance came from mostly Manufacturing Engineering, Industrial or general engineering departments. Most respondents came from Ph.D. granting institutions 123 (67.6 %), M.S. accounted for 27 (14.8%) and B.S. 32 (17.6%). Since about 350 schools offer engineering degrees in the US, the 133 US academic surveys appear to be a pretty good sampling. About 54% of the academic respondents reported that 25% or less of their fellow department faculty participate in the planning, coordinating and monitoring of the design stem as shown in Table 3.

Industrial Demand

Industry respondents who check marked topics and activities as "Very Important were counted and then ranked. The individual counts and ranks of the top ten topics are listed in Table 4. The top five activates are listed in Table 5. Looking at the rankings, when one considers industry's emphasis on quality, it's no surprise that Teamwork, Engineering design Specifications and Design for Manufacture and Assembly rank high.

Table 3. Participation in planning, monitoring and coordinating the design stem.

Participation (%)	#	%
100	10	5.5
75	14	7.7
50	38	20.9
25	93	51.1
0	6	3.3
don't know	21	11.5
Total	182	100.0

Table 4. Top ten topics most important to industry.

Q	Topic	#	Rank
24	Teamwork	748	1
3	Engineering design specifications	729	2
10	Design for manufacture	724	3
19	Overall design process	667	4
9	Design for assembly	642	5
7	Creativity methods	598	6
22	Project management	595	7
18	Product testing	580	8
17	Tolerancing	548	9
13	Solid modeling	515	10

Table 5. Top five activities most important to industry

Q	Activity	#	Rank
34	Team design project(s)	695	1
25	Open-ended problem solving	554	2
31	CAD-Solid Modeling	541	3
33	Interdisciplinary design project(s)	514	4
37	Design report(s) – Written	465	5

Academic Supply

Those respondents who check marked Y's (yes), for each question, were counted for freshman thru senior years. For example, an institution that covered a topic or activity in all four years would have had a score of 4 (four yes-es). These were summed for all institutions and all topics, and then ranked. While the 4-year-sum may not be a perfect measure of academic "supply," it does indicate a certain amount of institutional emphasis for each design topic or activity. The maximum total for a question is 728 (182 schools, four years).

Topics such as: Teamwork, Mathematical modeling, Literature / web searching, Engineering Design Specifications and Overall Design Process top the list as shown in Table 6. Open-ended problem solving, written Design Reports and Team Design Projects top the list of activities as shown in Table 7.

Table 6. Top ten most frequently taught topics.

Q	Topic	#	Rank
24	Teamwork	454	1
15	Mathematical modeling & analysis	409	2
8	Literature / web searching	407	3
3	Engineering design specifications	401	4
19	Overall design process	384	5
7	Creativity methods	354	6
13	Solid modeling	353	7
17	Tolerancing	283	8
10	Design for manufacture	263	9
18	Product testing	249	10

Table 7. Top five most frequent activities.

Q	Activity	#	Rank
25	Open-ended problem solving	428	1
37	Design report(s) - Written	407	2
34	Team design project(s)	385	3
36	Design report(s) - Oral	361	4
31	CAD-Solid Modeling	349	5

By comparing the differences in ranks we obtain an estimate of the demand versus supply gap for design education. The gap appears to be large for the following topics: Design for assembly (-9), Design for manufacture (-6), Quality Function Deployment/House of Quality (-6), Rapid prototyping (-5), Optimization methods (-5), Product marketing (-5) and Project management (-4). The activities in most demand appear to be: Interdisciplinary design project(s) (-7) and Industry based design project(s) (-4).

Note that the Teamwork score of 454 is 62% of 728. And that for the tenth ranked topic, Product Testing, 249 is 34% of 728. Granted, some topics may need to be covered only once before a student graduates, but the numbers do seem low. Due to the differences in the reporting schools such as semesters versus quarters, metropolitan versus residential, coop versus traditional, research versus comprehensive, and so on, it is no surprise that there are many viable approaches to achieving the "design stem," however.

Design Across the Curriculum

Listings of the most frequently taught topics and activities by year were also prepared and are shown in Table 8 and Table 9. Table 8 provides some indication of the topics and activities that are emphasized at various stages of an engineer's education. Looking down the freshman year columns of both tables we see topics and activities that are typical of "Introduction to Engineering," and or "Introduction to Engineering Design" and or "Engineering Graphics" courses. These appear to be continued in the sophomore year and junior year, but with Design for Manufacture and Assembly added in. And lastly, "Senior Design Project" and or "Senior Project" like courses appear to include a mixture of design process, specifications and project management wrapped up in a comprehensive experience. Unfortunately, the table is an accumulation of individual responses. Therefore, only in the aggregate do these topics appear in the top ten.

Table 8. Top ten topics by year.

Freshman	Sophomore	Junior	Senior
Lit. / Web searching	Teamwork	Math. modeling	Teamwork
Teamwork	Math. modeling	Teamwork	Overall design process
Overall design process	Literature / web searching	Design specifications	Design specifications
Creativity methods	Design specifications	Lit/web searching	Math. modeling
Solid modeling	Overall design process	Overall design process	Project management
Design specifications	Solid modeling	Solid modeling	Creativity methods
Tolerancing	Creativity methods	Creativity methods	Lit/web searching
Math. Modeling	Tolerancing	Design for manufacture	Solid modeling
Reverse engineering	Design for manufacture	Engineering economics	Design for manufacture
Product testing	Design for assembly	Function decomposition	Product testing

Table 9. Top five activities by year.

Freshman	Sophomore	Junior	Senior
CAD-2D	Open-ended prob. solv.	Des. report(s) - Written	Des. report(s) - Written
Open-ended prob. solv.	CAD-2D	Open-ended prob. solv.	Design report(s) - Oral
Creativity exercises	Des. report(s) – Written	Team design project(s)	Team design project(s)
CAD-Solid Modeling	Team design project(s)	CAD-Solid Modeling	Open-ended prob. solv.
Team Des. project(s)	CAD-Solid Modeling	Design report(s) - Oral	Industry D. Proj.(s)

Design Across the Curriculum – Reinforcement

To better understand which topics and activities were important enough to be reinforced by each school in subsequent years, an additional analysis of the data was prepared. Respondents whose school taught a topic/activity "at least once" and "more than once" were counted. The counts were then ranked. These are shown in Table 10 and Table 11. Notably Teamwork, design process, mathematical modeling and engineering design specifications appear to be the most reinforced topics. Design report(s) – Written, Open-ended problem solving, Team design project(s) and Design report(s) – Oral are the most frequently reinforced activities.

Table 10. Top Ten topics taught "at least once" and "more than once."

At least once	More than once
Teamwork	Teamwork
Engineering design specifications	Math. modeling & analysis
Overall design process	Overall design process
Math. modeling & analysis	Engineering design specifications
Solid modeling	Literature / web searching
Creativity methods	Creativity methods
Literature / web searching	Solid modeling
Engineering economics	Tolerancing
Project management	Design for manufacture
Design for manufacture	Product testing

Table 11. Top five activities taught “at least once” and “more than once.”

At least once	More than once
Design report(s) – Written	Design report(s) – Written
Team design project(s)	Open-ended problem solving
Design report(s) - Oral	Team design project(s)
Open-ended problem solving	Design report(s) - Oral
CAD-Solid Modeling	Creativity exercises

Demand versus Supply- Another Look

A comparison list was prepared using topics identified by industry as important and or very important. This was compared to Academia’s percentage of schools that taught the same topic more than once, as shown in Table 12. It appears that the supply and demand for Teamwork and Engineering design specifications is fairly balanced. However, industry demand may be somewhat unfulfilled for the following topics; Creativity methods, Project management, Design for manufacture, Design for assembly, Product testing and Tolerancing. The most notable being Design for assembly, product testing and design for manufacture.

Table 12. Demand and supply of the top ten design topics identified by industry.

Topic	Academic %	Industrial %	Difference %
Engineering design specifications	94.0	97.5	3.6
Teamwork	94.0	95.6	1.7
Overall design process	92.9	95.2	2.4
Creativity methods	87.9	94.3	6.4
Project management	85.7	94.3	8.6
Design for manufacture	82.4	93.3	10.9
Design for assembly	78.0	92.5	14.5
Product testing	76.4	90.5	14.1
Tolerancing	80.2	89.7	9.4
Literature / web searching	85.7	84.0	-1.7

A similar table was similarly prepared for the activities as shown in Table 13. From an activity perspective, demand and supply for Team design projects appears to be balanced. However, there is a significant gap for Interdisciplinary design projects and Individual design projects. In addition there appears to be an over supply of design reports and physical prototype fabrication.

Computer platforms

Industry and academe appear to be in sync with each other with respect to computer platforms as shown in the following Table 14.

Table 13. Demand and supply of design activities.

Activity	Academic %	Industrial %	Difference %
Team design project(s)	93.4	94.2	0.8
Open-ended problem solving	89.6	93.2	3.7
Design report(s) – Written	94.0	89.4	-4.6
Interdisciplinary design project(s)	74.7	87.3	12.6
CAD-Solid Modeling	84.6	85.7	1.1
Individual design project(s)	71.4	85.3	13.9
Industry based design project(s)	79.1	83.3	4.2
Creativity exercises	79.7	83.2	3.5
Design report(s) – Oral	91.2	81.0	-10.2
Physical prototype fabrication	82.4	79.2	-3.2

Table 14. CAD platforms.

	Academe		Industry	
Platform	#	%	#	%
PC	148	81.3	865	86.0
Unix	25	13.7	116	11.5
other	9	4.9	25	2.5
Total	182	100.0	1006	100.0

Comments

Academic respondents and 425 industrial respondents submitted approximately 100 comments. A cursory examination of the comments did not reveal anything particular. The comments were not classified or counted.

Making use of the data

Faculty may wish to examine both their program's breadth of "design" coverage and the emphasis of coverage. For example, does their program cover the breadth that industry desires? Does their program emphasize each topic or activity to the extent that industry does? If one of their program's objectives is to prepare students for various engineering positions throughout the US, then the data should be quite meaningful. If, on the other hand, their program is more focused to local needs the data will be less meaningful.

In addition, faculty might wish to discuss the data with their own faculty. Are the right design topics being taught and activities conducted in their program? Or, are the right topics and activities emphasized in the freshman, sophomore, junior and senior years? Considering the apparent lack of participation in planning the design curriculum as shown by the data, the survey results may stimulate "design" communication among faculty in the same program.

Lastly, industry representatives that advise academia may wish to discuss these data with their program chairs or faculty. For example, they might ask if and how their needs are being met currently and in the future? If anything, the survey results should at least be a means for industry representatives to initiate a dialog on design education.

Summary

- Academia appears to be meeting industry's demand for Engineering Design Specifications, Teamwork and Overall Design Process topics.
- There appears to be a supply gap, however, in academia's current coverage of Creativity Methods, Project management, Design for Manufacture, Design for Assembly, and Product Testing.
- Industry has a higher demand for Individual Design Projects and Interdisciplinary Design Project activities, in relation to Academia's current coverage.
- Academia appears to overemphasize oral and written design report activities.
- Design topics and activities are offered over all four years.
- A majority of respondents indicated that 25% or less of the department's faculty participates in planning, monitoring and coordinating the design stem.
- Personal Computers are the preferred choice of CAD platform in industry and academia as compared to Unix stations.
- Academia and industry should find the survey results useful for program planning.

Acknowledgements

In addition to the academic and industrial survey respondents, the following organizations and individuals were very helpful in making this study possible: ASME Design Engineering Division, ASME Design Automation Committee, ASME Manufacturing Engineering Division, ASEE Design Education Division, Richard Furness, Mark Gantor, Fred Goldfarb, John Klegka, Kemper Lewis, J. Liu, Daniel Segalman, and Filippo Salustri. For additional information and data summaries see: http://coen.boisestate.edu/REGGERT/

Bibliography

1. National Science Foundation, 1996. *Research Opportunities in Engineering Design*, NSF Strategic Planning Workshop Final Report, Washington, D.C.
2. Bannerot, R., 2002. "The Do's and Don'ts for Major Projects in an Introductory Design Course," Proceedings *of the 2002 American Society for Engineering Education Annual Conference and Exposition*, June, Montreal, Quebec.
3. Doepker P.E., A.P. Murray, 2001. "Experiences in Integrating the Product Realization Process into the Design Curriculum," Proceedings *of the ASME 2001 Design Engineering Technical Conference*, American Society of Mechanical Engineers, Pittsburgh, PA.
4. LeMaster, R., R. Helgeson, J.D. Sterrett. 2002. "Integration of Design Throughout the Curriculum of a BSE Program," *Proceedings of the 2002 American Society for Engineering Education Annual Conference and Exposition*, June, Montreal, Quebec.
5. Eggert, R.J., and S. Tennyson, 2000. **"**A Survey of Computer-Integrated Design and Manufacturing Skills for Engineers,**"** *Proceedings of the 2000 ASME International Mechanical Engineering Congress & Exposition*, American Society of Mechanical Engineers, November, Orlando, Fl.
6. Eggert, R.J., S. Tennyson, D. Bunnell. 1998. "Designing Across the Curriculum: Linking Sophomores to ME," *Proceedings of the 1998 ASEE Annual Conference & Exposition*, June, Seattle, WA.
7. Davis, D.C., K.L. Gentili, M.S. Trevisan, D.E. Calkins. 2002 "Engineering Design Assessment Processes and Scoring Scales for Program Improvement and Accountability," *Journal of Engineering Education*, ASEE, Washington, D.C.
8. United States Bureau of Labor Statistics: http://stats.bls.gov/

Biographical Information

RUDY J. EGGERT is a Professor in the Department of Mechanical Engineering at Boise State University. His research interests include Engineering Design, Optimization, Design Theory and Methodology, Machine Design, and Probabilistic Analysis.