

AC 2007-2005: ENGINEERING DESIGN: ARE WE TEACHING THE RIGHT STUFF?

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Engineering Design: Are We Teaching the Right Stuff?

Abstract

Developing an undergraduate engineering design curriculum can be a challenge. Using the continuous improvement process adopted by ABET 2000, engineering programs typically consider: which outcomes our program should set out to achieve, which assessment measures to use, and how we should make revisions to develop our program. To achieve the “outcomes” program faculty carefully develop curricula including what should be taught, and also when and how it should be taught.

This study reviewed literature, beginning with 1991, covering capstone design and design education in general. The composition of respondents varies such as group surveys covering capstone design among different disciplines and other, more narrowly focused surveys. In summary the studies indicate that since Dixon’s seminal article in 1991 we have seen: increased emphasis in integrating the Product Realization Process, improvement in the working definitions of design and design processes, an increase in the number of design topics taught in capstone design from 1994 to 2005, but, an apparent and dramatic decrease in the number of design topics from 2003-2006.

1.0 Introduction

Developing an undergraduate engineering design curriculum can be a challenge for any institution. Using the continuous improvement process adopted by ABET 2000, we typically consider: which outcomes our program should set out to achieve, which assessment measures to use, and how we should make revisions to develop our program.

Criterion 3, of ABET’s 2007 Criteria for Accrediting Engineering Programs¹, lists 11 desirable outcomes lettered (a) thru (k). Outcome (c), specifically deals with engineering design, stating that graduating students should have: “an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability”

Criterion 4 goes on to list three subject areas: “(a) one year of a combination of college level mathematics and basic sciences (some with experimental experience) appropriate to the discipline, (b) one and one-half years of engineering topics, consisting of engineering sciences and engineering design appropriate to the student's field of study..., and (c) a general education component that complements the technical content of the curriculum and is consistent with the program and institution objectives.”

Criterion 4 further states that: “Engineering design is the process of devising a system, component, or process to meet desired needs. It is a decision-making process (often iterative), in which the basic sciences, mathematics, and the engineering sciences are applied to convert resources optimally to meet these stated needs.”

The changeover to these new standards, first occurring in ABET 2000, provides significant latitude for each institution to customize the content and delivery of its programs and thereby meet the needs of its stakeholders. However, it unfortunately places a significant burden on an institution's faculty to correctly determine:

1. which design topics should be taught (i.e. principles, methods, theories etc.),
2. when in the typical four-year program they should be taught, and
3. which pedagogical methods best achieve the outcomes.

What we teach will naturally affect our students' achievement of desired program objectives. For example, if we want our students to be effective communicators we need to "teach" communication topics including verbal presentations, written reporting, graphics, technical drawings, and presentation of engineering mathematics and numerical data. How we teach communication is also important such as having the appropriate mixture of lectures, active learning, homework, projects and laboratories. Similarly, a series of progressive reinforcements over the four year curriculum is ideal.

This paper, however, will primarily focus on efforts to determine which design topics should be taught.

2.0 Before ABET 2000

In 1991, Dixon² wrote a seminal article discussing the state of engineering design. He suggested that we broaden the scope of engineering design to include the entire product realization process (PRP) to include design and manufacturing processes that convert information, materials, and energy into a finished product. He described a general state of intellectual stagnation pointing out that:

"A major obstacle to fixing engineering design education is the mistaken idea that engineering design is an art or a skill that can be learned only through experience..." and further that

"... (design) is largely a cognitive activity based on knowledge – of facts, science, engineering science, design, manufacturing principles, processes, strategies, and business organizations."

He also listed other obstacles including: a lack of support for design research, engineering educators not understanding design versus analysis, not knowing the difference between design experience and education, limiting design education mostly to functional performance analysis, and unrealistic thinking about what can be taught in a 4-year curriculum.

In a second-part article, Dixon³ went on to propose that because we have limited time in the four-year program, we should focus on teaching "fundamentals" of design and restrain from teaching merely best practices. He developed a list of fundamentals of engineering design science as shown in Table 1, derived from current best practice and research to that time.

Table 1. Fundamentals of engineering design science (adapted from Dixon³)

Item	Fundamental
1.	The business context of engineering design (i.e. PRP)
2.	Concurrent engineering and team participation principle
3.	Manufacturing
4.	Analysis and prototyping
5.	Statistics
6.	Systems design
7.	Computer aided design
8.	Design theory and methodology
9.	Component design and optimization
10.	Assembly design and tolerances
11.	New information and learning

Dixon proposed that the fundamentals could be arranged into a curriculum of perhaps 6 courses: 1.) product realization processes, 2.) manufacturing processes, 3.) design of mechanical components, 4.) design of mechanical assemblies, 5.) concurrent multifunctional team design and 6.) information retrieval and learning.

In 1993, Todd et. al.⁴ suggested refinements to senior capstone design courses, to address the difficulty that businesses were having in competing in world markets using traditional design and production methods. They described a product development process which included: functional specifications, concept generation, concept evaluation and selection, design, robust engineering, process planning, prototype development and testing, production and acceptance testing. They suggested that educating students in these aspects of the PRP would improve their student's preparation for employment.

In 1995, Todd et. al.⁵ presented results of a national survey of capstone engineering courses conducted in 1994. The largest group of respondents came from mechanical engineering, however, civil, industrial and electrical programs were fairly represented. The survey included information on faculty involvement, industrial involvement, duration of projects, instruction hours per week, and most pertinent to this paper, the most frequently taught subjects as shown in Table 3. The rightmost column labeled “%” represents the proportion of responding schools that taught the subject in their capstone course. The table is one of the earliest quantitative reports of design topics and or subjects actually taught across North America. It provides an important glimpse of specific engineering design topics that can be included in a design curriculum.

In 1995, ASME⁶ reported on 56 “best practices” of engineers as perceived by industry. Table 2 lists the top 20. Note that Dixon used current best practice in 1991 to develop his list of fundamentals of engineering design. Many of the items listed in the table can be taught from three additional perspectives: as knowledge, as skills and as attitudes. Therefore, the 20 categories below should not just be considered “best practices” but rather categories of knowledge, skills, attitudes and practices. And that perhaps, knowledge drawn from these topics can be used to develop a body of design “science” as Dixon proposed, and that only the best and most current “practices” be taught.

Table 2. Most frequently taught subjects in capstone design courses.

Item	Most Frequently Taught Subjects	%
1	Oral communication	61
2	Drawings, creativity, and concept generation	48
3	Teamwork essentials	44
4	Project planning and scheduling	42
5	Engineering ethics	40
6	Engineering economics	40
7	Developing and writing functional specifications	36
8	Safety in product design	33
9	Optimization	31

Table 3. Best practices of graduating B.S. engineers (ASME⁶)

Item	Best Practice
1.	Teams/teamwork
2.	Communication
3.	Design for manufacture
4.	CAD systems
5.	Professional ethics
6.	Creative thinking
7.	Design for performance
8.	Design for reliability
9.	Design for safety
10.	Concurrent engineering

Item	Best Practice
11.	Sketching/drawing
12.	Design for cost
13.	Application of statistics
14.	Reliability
15.	Geometric tolerancing
16.	Value engineering
17.	Design reviews
18.	Manufacturing processes
19.	Systems perspective
20.	Design for assembly

In 1997, Dutson et. al.⁷ conducted an extensive review of literature on the teaching of engineering design via project-oriented capstone courses. They suggested a breadth of topics, adapted from Banios⁸, that are often taught including: the profession (ethics, societies, registration, life-long learning), legal considerations, documentation and presentations, system development (needs analysis, trade-off analysis, requirements definition, design specification, test planning), design process (methodology, risk, verification/testing, quality assurance) and engineering project operations (phased system development, organization structures, management, interpersonal relations, proposals, work breakdown structures). The study made no mention as to the frequency with which the topics were taught (i.e. how widely adopted).

3.0 Design topics from 2000 thru 2005

In 2001, Doepker and Murray⁹ reported on their successful experiences integrating the product realization process into their design curriculum over a five-year period. In it, they described activities including: determining the customer's needs, developing specifications, generating conceptual designs and designing the final product. The activities spanned approximately four months and included phases of establishing the need, conceptual design, embodiment design and

final design. No mention was made however of specific topics that were taught in the capstone design course, or courses leading to the capstone. In 2006, Doepker¹⁰ followed up with an additional study covering 10 years of experience including the PRP in the design curriculum. While this article described a new conceptualization process and a discussion of decision analysis using modified Pugh's method and linear weighted rating, it also did not specifically identify design topics taught. One might infer however, that students were given background knowledge of the individual phases in the PRP and also given guidance with respect to project-management, teamwork, and communications.

In 2002, Davis et.al.¹¹ discussed engineering design assessment processes. In addition to teamwork and communication they developed useful rubrics to assess design process skills such as information gathering, problem definition, idea generation, evaluation, decision making, implementation, and process development. However, the paper did not list specific engineering design topics taught to prepare students in achieving these desirable outcomes.

In 2003, Eggert¹² conducted a national survey of engineering design topics taught and compared it with engineering design topics desired by industry. The results of this study are presented in Table 4. Twenty three topics were identified and surveyed. The percentage of industry respondents who considered the topic important or very important is presented in the first column. The proportions of faculty respondents teaching the topics are presented in the far right column. The third column was arbitrarily defined as a demand versus supply gap, that is industry demand versus academic supply. The shaded cells represent gaps of eight percentage points or larger.

Seven of the 10 gaps are over 10 percentage points. If we select only those topics considered important by industry (arbitrarily >79% or more of the respondents) then we find "important" gaps in: design for assembly, product testing, optimization, design for manufacture, and benchmarking of competitive products. Eggert¹³ conducted a follow-on national web survey to determine specific competencies relating to design for assembly and design for manufacture.

In 2005, Dym et. al.¹⁴ completed a literature review of engineering design thinking, teaching and learning. They adopted the following definition:

"Engineering design is a systematic, intelligent process in which designers generate, evaluate, and specify concepts for devices, systems, or processes whose form and function achieve clients' objectives or users' needs while satisfying a specified set of constraints."

They identified skills associated with "good designers" including the ability to tolerate ambiguity, maintain site of the big picture, handle uncertainty, make decisions, think as part of the team, and communicate in several languages of design. Additionally they suggested that the most important recommendation they could make was that both faculty and administrators make design pedagogy their highest priority. While their study did not specifically examine the breadth of engineering design topics being taught at North American universities, they're working definition of engineering design and their associated desirable skill set provide us with some building blocks for design curriculum development.

Table 4. Engineering design topics: demand and supply

Design Phase	Q	Topic	2003 National		
			Industry	Academia	Dif.
			%	%	%
Problem Formulation	1	Benchmarking of competitive products	79	69	10
	2	QFD/House of Quality	78	68	10
	3	Engineering design specifications	98	94	4
	4	Function decomposition	67	71	-4
	5	Function structure	72	63	9
Concept and Configuration	6	Reverse engineering	64	71	-7
	7	Creativity methods	94	88	6
	8	Literature / web searching	84	86	-2
	9	Design for assembly	93	78	15
	10	Design for manufacture	93	82	11
	11	Pugh's method	21	43	-22
	12	Weighted rating method	30	50	-20
	13	Solid modeling	83	88	-5
	14	Rapid prototyping	64	60	4
Parametric	15	Mathematical modeling & analysis	83	88	-6
	16	Optimization methods	79	65	14
Detail	17	Tolerancing	90	80	9
	18	Product testing	90	76	14
Other	19	Overall design process	95	93	2
	20	Patents, copyrights, trademarks	66	74	-8
	21	Engineering economics	81	86	-5
	22	Project management	94	86	9
	23	Product marketing	62	45	17

In 2005, Howe and Wilbarger¹⁵ conducted a national survey of engineering capstone design courses. The survey had good representation from chemical, civil/environmental, electrical, industrial, and mechanical/aerospace engineering programs and comprehensively examined faculty involvement in capstone courses, sources of projects, teams per project, students per project, project hours per week, strategies and sources of project funding, sponsor support and intellectual-property ownership. More importantly, they quantitatively examined the subjects taught in capstone design courses as shown in Table 5. We see that 11 topics are taught by 50% or more (shaded) of the responding programs. Note that many of the 24 topics listed in Table 5 have already been presented in the articles discussed in this paper. There are however, a few new and very important topics such as sustainability, risk assessment, and product liability.

Their study also compared the frequency of subjects taught in 2005 with the frequency of subjects taught in the 1994 study by Todd. Their results indicated an increase in frequency for eight of the nine topics. In other words their data show that engineering schools were teaching more design topics in 2005 than in 1994.

Table 5. Topics taught in Sr. Capstone Design (adapted from Howe & Wilbarger¹⁵)

Item	Topic Taught in Sr. Capstone Design	%
1	Written communication	87
2	Oral communication	83
3	Engineering ethics	76
4	Project planning and scheduling	72
5	Decision making	68
6	Teambuilding	66
7	Team dynamics	63
8	Engineering economics	61
9	Developing/writing functional specifications	56
10	Safety in product design	52
11	Leadership	50
12	Standards and regulations	49
13	Drawing/creativity/concept generation	48
14	Analysis tools	46
15	Intellectual-property/patents	45
16	Prototyping and testing	37
17	Optimization	34
18	Sustainability	29
19	Manufacturing processes	29
20	Risk assessment	29
21	CAD design and layout	29
22	Product liability	24
23	Quality function deployment	17
24	Other	13

4.0 Design topics in the western U.S.: What happened from 2003-2005?

During a 2005/2006 sabbatical the author surveyed 19 mechanical engineering departments located in Washington, Oregon, California, Arizona, Utah, and Idaho, 17 by in-person campus visits and two by phone. A list of the schools is presented in Table 6 and a map of their geographic distribution is shown in Figure 2. The site visits were helpful in detailing specific aspects of their design curriculum including their support infrastructure (i.e. project labs, computer labs, design studios, machine shops, classrooms and support staff).

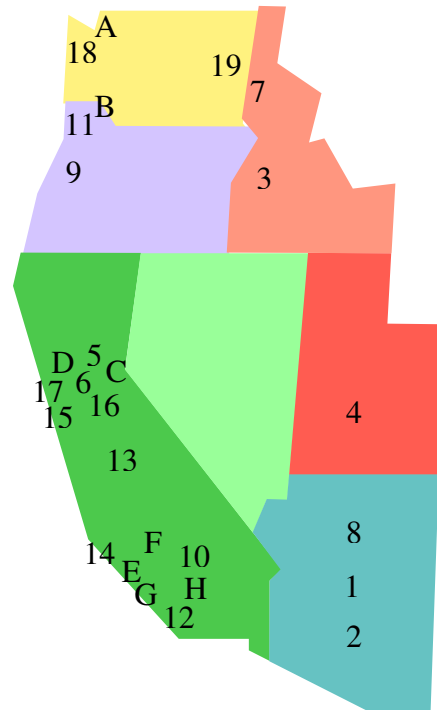
Although anecdotal, the site visits proved eye-opening. There were schools that had quite simple approaches to design such as a single capstone “design” course. Others, with more comprehensive programs, introduced design early in the curriculum, following up with a design theory and methods course in the sophomore or junior year, then concluding with a two semester senior capstone design course. There were hand-on approaches, including prototype fabrication versus paper design only. There were some schools with non-tenure track faculty in charge of capstone design. There were industry sponsored projects, student and or faculty initiated projects. Notably, the majority of schools required a manufacturing processes course, often with hands-on labs or “boot-camps.” There were courses using established design textbooks versus

those using handouts or web posted notes. There were schools with extensive administrative and machine shop and or facilities infrastructures versus those with limited resources. There were schools struggling with increased student enrollements and schools with reductions in design “teaching” faculty.

Table 6. Western universities in study

	University
1	Arizona State University
2	University of Arizona
3	Boise State University
4	Brigham Young University
5	California State University – Chico
6	University of California - Davis
7	University of Idaho
8	Northern Arizona University
9	Oregon State University
10	California Polytechnic – Pomona
11	Portland State University
12	University of California - San Diego
13	California Polytechnic – SLO
14	University of California - Santa Barbara
15	Santa Clara University
16	California State University – Sacramento
17	Stanford University
18	University of Washington
19	Washington State University

Figure 2. Geographic distribution.



A number site visits to manufacturing companies were made while in each metropolitan area including the eight listed in Table 7 that employ engineers dealing with issues in design for manufacture and or assembly. These are also shown on Figure 2 as lettered items. Interviews with representatives of the companies confirmed the need for engineering design education, particularly design for assembly and design for manufacture. Numerical data obtained from the small sample size were insufficient to be included in this report.

Table 7. Companies visited during 2006 Western States pilot study.

	Company Name	Location	Products
A	Boeing Aircraft	Seattle, WA	Commercial airplanes
B	Freightliner	Portland, OR	Trucks
C	Aerojet	Sacramento, CA	Rocket motors
D	BAE Systems	San Jose, CA	Tanks,
E	Clipper Wind Power	Santa Barbara, CA	Wind turbine/generator systems
F	Walt Disney Imagineering	Los Angeles, CA	Theme Parks/Amusement rides
G	Northrop Grumman	El Segundo, CA	Military aircraft
H	Hewlett Packard	San Diego, CA	All-in-one printers

During the university visits, an on-site survey was conducted to determine which design topics were regularly required and taught in their undergraduate Mechanical Engineering program. The topics were drawn from the 2003 study by Eggert¹¹ and represent subjects typically taught in some or the entire four-year curriculum. These were compared to the 2003 survey responses that were gathered from 183 engineering faculty and are shown in Table 8 below.

A demand/supply gap metric was created by computing the difference between industry's desire for a design topic and academia's teaching of that topic. An arbitrary difference of 8 points was used to shade the chart above and thereby notate more significant gaps. Ten gaps were identified in the 2003 study. The number of gaps appears to have grown to eighteen, a 70% increase.

Disregarding the industry gap analysis, one can examine academia all by itself. For example, by comparing the number of topics taught in 2003 versus 2006. In Table 8, the 2006 Academia column cells were shaded when its cell value was smaller than 2003. A smaller number means that fewer universities were requiring that topic to be taught in the undergraduate curriculum in 2006 versus 2003. Note there was a decrease in 20 out of 24 topics (83.3%). Only four design topics were taught more frequently. This appears to contradict the 1994-2005 comparison discussed in the Howe and Wilbarger survey, where they showed an increase from 1994-2005.

We can also count the number of topics taught by over 50% of the responding universities. In 2003 we found 21 topics being taught by 50% or more of the schools (out of a max of 23 topics). In the 2006 sample, we found that that number dropped to 15, a 29% drop in topics taught.

The author discovered another interesting situation during the one-on-one interviews. Three programs (out of the 18, or 16%) had hired full-time non-tenure track and or part-time adjunct professors to teach their senior design capstone and in some cases, other design courses. In all three cases, the positions had previously been tenure track. At another institution, the host mentioned that the new university administration wanted to increase emphasis on funded research by hiring research faculty, with little or no teaching load. The result was that some design courses have not been taught or not likely to be taught in the coming years.

Assuming that the 19 western universities surveyed in 2006 represent a fair sample of the 183 universities studied in 2003, then a major question arises. Why did we see a significant drop in design topics being taught? Was the drop because:

1. design curricula were downsized (presumably because they met stakeholders' needs),
2. fewer tenure-track design faculty were available to teach design,
3. faculty lost interest in teaching design topics,
4. stakeholders were not being correctly assessed, or
5. other?

Since most ABET accredited programs are on a six year cycle, 2006 marked the first year that everyone was on the new continuous improvement program. One reason for the drop in the number of topics taught could be because each program made refinements to their curriculum actually reducing design content, because pre-ABET 2000 curricula were somewhat redundant or

unnneeded. And that the design content pendulum needed to swing back to a more moderate position?

Table 8. Demand and supply of design topics.

Q	Topic	2003 National			2006 Western	
		Industry	Academia	Dif.	Academia	Dif.
		%	%	%	%	%
1	Benchmarking of competitive products	79	69	10	53	26
2	QFD/House of Quality	78	68	10	63	15
3	Engineering design specifications	98	94	4	89	8
4	Function decomposition	67	71	-4	53	15
5	Function structure	72	63	9	5	67
6	Reverse engineering	64	71	-7	32	33
7	Creativity methods	94	88	6	74	21
8	Literature / web searching	84	86	-2	89	-5
9	Design for assembly	93	78	15	47	45
10	Design for manufacture	93	82	11	42	51
11	Pugh's method	21	43	-22	42	-21
12	Weighted rating method	30	50	-20	63	-34
13	Solid modeling	83	88	-5	89	-6
14	Rapid prototyping	64	60	4	53	12
15	Mathematical modeling & analysis	83	88	-6	26	56
16	Optimization methods	79	65	14	21	58
17	Tolerancing	90	80	9	79	11
18	Product testing	90	76	14	68	22
19	Overall design process	95	93	2	84	11
20	Patents, copyrights, trademarks	66	74	-8	84	-18
21	Engineering economics	81	86	-5	37	44
22	Project management	94	86	9	84	10
23	Product marketing	62	45	17	21	41
24	Teamwork	96	94	2	89	6

Gaps 10 18

Another reason for the reduced number of topics is perhaps captured in the statement “quantity is not as important as quality.” Perhaps some programs are doing a “better” job at teaching “less” design. Since each program has not had many cycles of continuous improvement, we may not know yet whether our “stakeholders” really agree.

It might be also argued that some of the design topics listed in Table 8 relate to depth, not just breadth. For example, to improve the quality of engineering design specifications we can utilize function decomposition and or the House of Quality (HoQ). If we can agree that engineering design specifications is a fundamental design topic, then both function decomposition and the HoQ could be considered depth rather than breadth. Therefore, we may actually be reducing the depth and “quality” of design education.

One contributing factor may be that design faculty usually constitute a minority of the typical department total. We have seen in survey after survey, how only a small number from each program actually teach design courses or are “involved.” Could it be that our own community of design educators has not been able to persuade our own departments, that a solid design curriculum will not only meet minimum ABET standards, but more importantly, prepare our students for careers in a global work environment?

Unfortunately the answers to these questions will have to wait for the next study.

5.0 What design topics should we be teaching?

We can argue that the thermal sciences in mechanical engineering include a core of fundamentals including thermodynamics, fluid mechanics and heat transfer. We can suggest that for the motion/structures stem, mechanics of materials and machine design are brimming with fundamentals, too. And lastly, consider how engineering statics is important for both of these stems. Then, may we not also ask, for example, “what are the fundamentals of design for mechanical engineering, or civil engineering, etc?”

Perhaps one of the first tasks is to decide what constitutes a design topic? If we examine ABET’s definition of design along with that of Dym et. al., we might suggest that engineering design topics deal with one or more of the following:

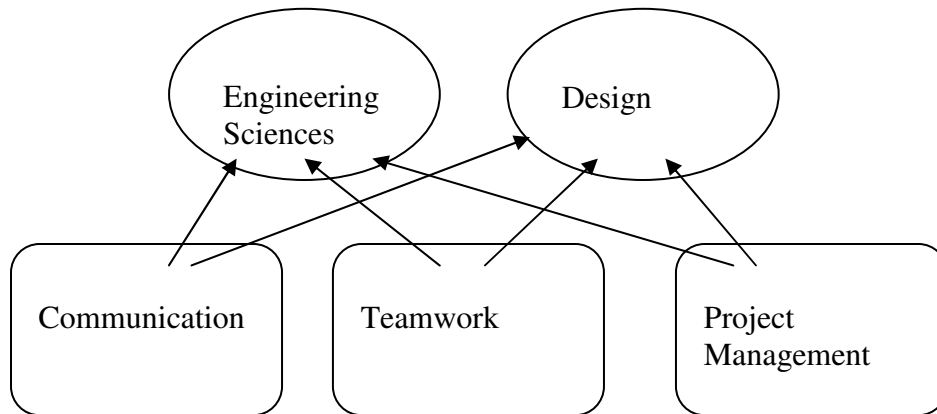
- Gathering and interpreting information,
- Determining constraints
- Generating alternatives
- Analyzing alternatives
- Evaluating alternatives and
- Making decisions

As engineers, we do design as individuals but more typically, we work in organized groups such as teams. Shouldn’t we therefore develop design knowledge, skills and attitudes that will facilitate working with others? For example, don’t we need group methods for gathering information, generating alternatives and making decisions? A group may be defined as a collection of people, whereas a team can be defined as a coordinated group. It is not enough to develop creativity in an individual, or analysis skills in an individual. Not only is there synergy in teamwork, but we also find built-in problem resolution such as during joint development of a project work scope, budget and schedule. Note that we would like all groups to work as teams, but we can’t guarantee it. Therefore, let’s face the fact that groups do exist. Because much of our design work interfaces with others in the PRP we need to have group or team methods and practices that facilitate design activities or processes.

Communication, teamwork and project management skills are central to group design success. For example, groups that have developed good teamwork skills usually complete design tasks quicker and better. This can also be said for communication and project management. We can also use these skills in doing experiments, or constructing a bridge, or repairing a steam turbine. Strictly speaking, they are not merely “design” topics. Rather, much like mathematics and the natural sciences, we could categorize them as core topics that provide knowledge, skills and

attitudes for the engineering sciences as well as design. And further, that they help students to achieve many of the (a) thru (k) program objectives spelled out in ABET Criterion 3. As evidence of their importance, we find that many engineering disciplines present these topics early in the freshman or sophomore years so that students can take advantage of their new skills in the remaining course work as well as after graduation. We can show the facilitating nature of these three topics in Figure 3.

Figure 3. Communication, teamwork and project management facilitate design.



As a second task, we can create a comprehensive list of design topics and facilitating topics as shown in Table 9, by consolidating the design topics discussed in the papers by Dixon, Howe and Eggert. Needless to say that teaching all of these topics in one or more courses would be a major challenge for any school. Also, we might ask which faculty members have the superhuman capabilities to teach all of these topics effectively. Recall that Dixon suggested six courses to cover the fundamentals.

While many of the “design” topics may be truly identified in design theory and methodology, a number of them such as sketching, optimization and risk assessment might be somewhat more general. Communication, teamwork and project management are listed at the bottom of the table along with other facilitating topics. Examples of subtopics with these can be found in Eggert.¹⁶ Each of the topics has been roughly categorized into one or more of the five phases of design including formulation, concept design, configuration design, parametric design and detail design.

There are notable differences between engineering disciplines. For example, civil engineering and electrical engineering may not need to understand the basics of manufacturing processes as mechanical engineers do. Therefore, we would probably agree that not all the topics will find acceptance by all the disciplines, that we do not share a common core of design fundamentals at all, other than the most simplified overall design process.

And lastly, we meticulously prepare a sequence of topics for our own department, grouped into new courses, or modules stuffed into existing courses, taking full advantage of existing faculty and the college’s infrastructure. And if we did our homework carefully, our department colleagues buy into our plan. The change over to continuous improvement starting with ABET 2000, provides each engineering program the opportunity to tailor its curriculum, including

engineering design, to meet their discipline (i.e. program) specific, local, regional, national and or international needs of its stakeholders.

Table 9. Comprehensive list of design topics and facilitating topics.

	problem formulation	concept design	configuration design	parametric design	final design
Design Topic					
Overall design process	x	x	x	x	x
Decision making (Pugh's, weighted rating)	x	x	x	x	x
Business context, product realization process (PRP)	x	x	x	x	x
Benchmarking of competitive products	x				
Function decomposition/diagram	x				
Quality Function Deployment / House of Quality	x				
Reverse engineering	x				
Engineering design specifications	x				
Function structure/diagram		x			
Creativity methods(brainstorming, checklisting)		x	x		
Sketching/drawing	x	x	x		
CAD design, solid modeling			x	x	x
Design for Assembly			x		
Design for Manufacture (design for cost)			x		
Design for Safety, product liability	x	x	x	x	x
Optimization methods			x	x	
Analysis tools (CAE, statistics, simulation)				x	
Prototyping (standard & rapid) and testing				x	x
Tolerancing (dimensioning, geometric)					x
Intellectual property (patents, copyrights, trademarks)					x
Design reviews	x	x	x	x	x
System design	x	x	x	x	x
Sustainability design	x	x	x	x	x
Codes, standards and regulations	x	x	x	x	x
Risk assessment	x	x	x	x	x
Facilitating / Supporting Topics					
Communication (oral, written, graphical, mathematical)	x	x	x	x	x
Teamwork (teambuilding, team dynamics, leadership)	x	x	x	x	x
Project Management (planning, scheduling, budgeting)	x	x	x	x	x
Engineering economics	x	x	x	x	x
Engineering ethics	x	x	x	x	x
Manufacturing processes	x	x	x	x	x
New information & learning (literature, web)	x	x	x	x	x

In the long run, if we do our assessments correctly, we will ultimately evolve successful curricula.

6.0 Conclusions

As Howe & Wilbarger, and Todd et. al. have pointed out, capturing trends in a single survey is difficult. This study has reviewed literature covering capstone design and design in general. The composition of respondents varies between groups with the capstone surveys being quite broad and the Eggert surveys more narrowly focused on mechanical engineering. In summary however, since Dixon's article in 1991 we have seen:

- increased emphasis in integrating the Product Realization Process,
- improvement in the working definitions of design and design processes,
- an increase in the number of design topics taught in capstone design from 1994 to 2005,
- but, an apparent dramatic decrease in the number of design topics from 2003-2006

7.0 Acknowledgements

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