

## **2006-2278: DESIGN IS DESIGN IS DESIGN (OR IS IT?): WHAT WE SAY VS. WHAT WE DO IN ENGINEERING DESIGN EDUCATION**

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# Design is Design is Design (or is it?) What We Say vs. What We Do in Engineering Design Education

## Introduction

At the undergraduate level, design attracts and excites students as they are drawn to the creative possibilities of the field of engineering. For the professional engineer, compelled to synthesize novel and effective solutions to difficult problems while operating at the limits of existing theoretical and practical knowledge, design is the dual source of great challenge and prime satisfaction. Design is one of the most fundamental, identifiable and enjoyable aspects of engineering practice, whether in industry or the academy. Nevertheless, while the importance of design is widely acknowledged, there is discord associated with efforts to *define* it.<sup>1</sup> The challenge is not that we lack a definition of design but that we have them in abundance. While engineering design research and engineering design practice benefit from the multiple perspectives and methods afforded by numerous definitions, the benefit to engineering design education is dubious. Indeed, the efficacy of engineering design education may be diminished by the lack of a common definition. Pedagogy and its assessment rely on shared definitions of the common corpus of knowledge that is to be learned. It is our contention that a common definition of design is the necessary precursor to

- (1) description and implementation of engineering design instruction in a single *class*,
- (2) the development of coherent engineering design experience across a *curriculum* and
- (3) the assessment and assurance of a consistent engineering design education experience across a *discipline*.

The research presented in this paper focuses on mechanical engineering design and is composed of two parts. The first is quantitative, wherein we attempt to understand where and when in the curricula design appears in the undergraduate mechanical engineering curricula of five U.S. universities. The design class is the unit of inspection in this quantitative phase. In the qualitative second phase of the research, we dissect individual classes within each of the curricula with the intention to understand what specific content and activities make them “design classes.” It is from the qualitative analysis that we have extracted a pragmatic and substantive definition of engineering design education. As distinguished from the theoretical, this grounded definition grants insight into the reality of design education as practiced. Through analysis, a descriptive language is developed to depict design, as it exists in the classroom, offering a striking contrast to existing theoretical or conjectural definitions of design. It also provides the opportunity to objectively compare expressed design education goals to actual educational practice.

## Background

This work finds its origins in the Preparations for the Professions Program (PPP) initiated in 1999 by the Carnegie Foundation for the Advancement of Teaching.<sup>2</sup> This initiative was driven by a desire to understand and describe formal efforts to educate professional practitioners. The first phase of the program focused on three professions—law, the clergy and engineering. The research presented here began within the engineering component.

In the first stage of the PPP engineering study, documents from a national survey and ABET self-studies from 50 engineering schools (over 100 programs) were reviewed. This stage granted

a broad view of teaching and learning practices in engineering education in the U.S. From this larger group, seven schools were selected for further, in-depth investigation via site visits. The selected schools are located in all regions of the U.S. and include a wide range of institutional types—a small stand-alone school of engineering, a large public engineering school, several university-based programs, a Catholic university, and a school that serves many first-generation college students and transfer students. Rather than a comprehensive or totally representative view, examination of this selection offers a reasonable picture of the state of mechanical engineering education. It was from these schools that the programs discussed in this paper were drawn as subjects of an even narrower investigation into mechanical engineering *design* education.

Our working definition of engineering design was drawn from a recent article in a special issue of the *Journal of Engineering Education* focused on engineering education research:

*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.<sup>3</sup>

This definition, along with the research perspective it reflects, operates under the premise that design, in substantial proportion, is a complex and intellectual activity. It recognizes design both as a practice and a way of thinking. By extension, design education would be expected to give learners an opportunity to engage in design as an activity, or if you will, practice, and explicitly guide the intellectual process in objective and assessable ways. In this view, design is both theory and practice. It is this dualistic view of design that guided the present investigation of the state of undergraduate engineering design education in the U.S.

### **Research Methodology**

Data for this study were extracted from the ABET self-reports prepared by the respective programs for the purpose of engineering accreditation review using the new ABET EC 2000 Criteria.<sup>4</sup> For each program, the Basic-Level Curriculum (BLC) Table (see Figure 1) and Course Syllabi (see Figure 2) were collected and examined. In addition, when necessary, online course syllabi and curricula were consulted to supplement ABET course and curricular data.

**Table 1. Basic-Level Curriculum  
Mechanical Engineering**

Year; Semester or Quarter	Course (Department, Number, Title)	Category (Credit Hours)			
		Math & Basic Sciences	Engineering Topics	General Education.	Other
			Check if Contains Design (✓)		
Freshman Fall					
	CIV		( ) 5		
	Writing		( ) 3-5		
	Math 41-Single Variable Calculus	5	( )		
	Physics 41-Mechanics	3	( )		
Freshman Winter					
	CIV		( ) 5		
	Writing		( ) 3-5		
	Math 42-Single Variable Calculus	5	( )		
	Physics 43-Electricity	3	( )		
Freshman Spring					
	CIV		( ) 5		
	Math 51-Linear Algebra & Differential Equations	5	( )		
	Physics 45-Magnetism	3	( )		
	E 14-Applied Mechanics		5 (✓)		
Sophomore Fall					
	ME 101-Visual Thinking		3 (✓)		
	E15-Dynamics		5 ( )		
	E155A- Differential Equations in Engineering <i>OR</i>	4	( )		
	Math 52-Calculus of Several Variables	5	( )		
	E 40-Introductory Electronics		5 ( )		

**Figure 1: Sample ABET Basic-Level Curriculum Table (Excerpt)**

This table presents the first four quarters of a typical undergraduate program in Mechanical Engineering at this school. It shows what courses a student would take and when in their four-year tenure they would likely take them. The table also contains the number of units associated with course and identifies it as belonging to one of four categories: Math & Basic Science, Engineering, General Education or Other. Within the Engineering category, a checkmark is used to designate whether a class is a design class.

**Course Number:** [REDACTED]

**Course Title:** Stress, Strain and Strength

**Course Description:**

This course provides an introduction to the mechanics of failure in engineering structures and components. Building on the students' prerequisite knowledge of free body diagrams and elementary mechanics of materials, the course introduces methods for analyzing complex stress states in mechanical systems. Static and dynamic failure modes, including plastic yielding, brittle failure, fracture, fatigue and buckling, are described and stress- and strain-based failure criteria are developed. Students analyze components for potential failure and produce designs to avoid failure. Some experimental demonstrations of material behavior are provided. Occasional guest speakers from industry provide talks on themes coordinated to classes.

**Prerequisites:**

[REDACTED] Statics and Strength of Materials

**Course Objective:**

To provide students with:

1. Better understanding of the important role that structural analysis plays in design,
2. Improved analytical skills for design, particularly in the area of evaluation of structural integrity,
3. Understanding of the mechanical conditions and mechanisms that cause failure of materials including yielding, fracture and fatigue.

**Topics Covered:**

Review of basic mechanics of materials and engineering properties of structural materials. Stress concentrations and their avoidance through design. Pressure vessels. Static failure theories for ductile and brittle materials, including plastic yielding and brittle fracture criteria. Introduction to fracture mechanics. Review of surface failure mechanisms including corrosion, fretting and wear. Structural failure by global and local buckling of columns and plates. Introduction to material failure by fatigue; fatigue failure criteria and life prediction methods. Case studies in failure of structural components emphasizing applications to mechanical design.

**Class/Laboratory Schedule:**

The course meets for lecture 85 minutes two times a week. In addition, it meets for a problem-solving session 1 time a week for 90 minutes.

**Relation of Course to Program Objectives:**

- Objective (a): provides the student with the ability to apply knowledge of mathematics, science, and engineering
- Objective (c): provides the student with the ability to design a system, component, or process to meet desired needs
- Objective (e): provides the student with the ability to identify, formulate, and solve engineering problems
- Objective (i): provides the student the ability to recognition of the need for, and an ability to engage in life-long learning
- Objective (k): provides the student ability to use the techniques, skills, and modern engineering tools necessary for engineering practice

**Contribution of Course to Meeting the Professional Component:**

Engineering Topics and Design: 3 credit hours

**Prepared by:** [REDACTED]

**Date:** March 28, 2000

**Figure 2: Sample ABET Course Syllabus**

This is an example of the course syllabi included in the ABET self-report for each program. It includes a detailed description of the course as well as the relationship of the course to specific ABET objectives.

ABET course syllabi are prepared for each course in the BLC Table as well as for relevant elective and support courses. These syllabi are standardized; for each course the following information is provided, at a minimum:

- Department, number, and title of course
- Designation as a 'Required' or 'Elective' course
- Course (catalog) description
- Prerequisite(s)
- Textbook(s) and/or other required material
- Course objectives
- Topics covered
- Class/laboratory schedule, i.e., number of sessions each week and duration of each session
- Contribution of course to meeting the professional component
- Relationship of course to program outcomes
- Person(s) who prepared this description and date of preparation

For the quantitative phase of this study, the information contained in tables for all of the programs was compiled in a spreadsheet. This enabled comparisons of programs based upon the number and distribution of design in the curricula on a course basis, as well as an academic credit basis.

In addition to the table for each program, the course syllabi were relied upon heavily for the qualitative phase of research. For each class designated as a design class in a BLC table, the corresponding syllabus was examined to determine the basis for this designation. Specifically, the course description, objectives, topics and contributions were examined to identify content and activity that generated and justified the label of "design."

The quantitative analysis was guided by two assumptions:

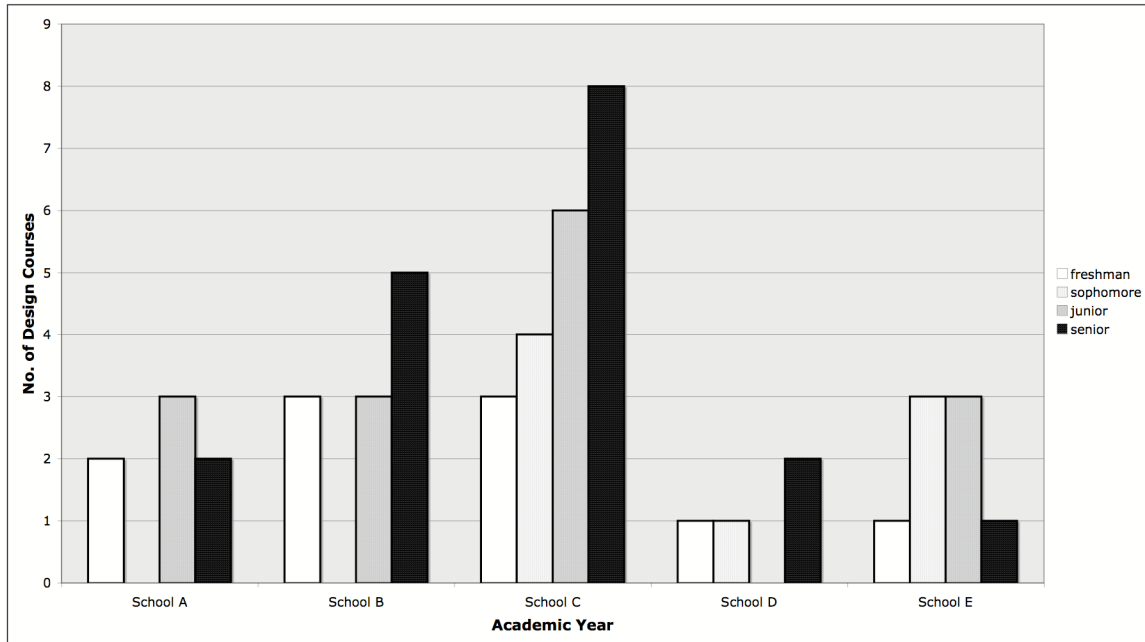
- (1) Design checkmark designations are valid
- (2) Design checkmark designations are equivalent

Both assumptions are quite simple, yet neither is trivial. The assumption that each design "checkmark" designation on the BLC tables is valid asserts that each identified class is, in fact, a design class. Rather than questioning such assertions or imposing a predetermined external definition of design, we accept that the definition used to designate the class was correct. As such, the BLC table offers pointers to all of the design content in the represented curriculum, as identified by the instructors of each individual class.

Our second assumption is that the interpretations of "design" reflected by each of these checkmarks are similar enough to be comparable. Such an assumption is necessary if we are to make any comparisons across classes and curricula. This is not a novel assumption, but reflects ABET's greater assumption that these tables and self-reports may be used as part of an objective means of assessment and accreditation.

### **Findings and Discussion:** *Quantitative Analysis*

The extensive data collected were analyzed to produce charts such as that shown in Figure 3, which depicts the number of design courses taken in each program each academic year.



**Figure 3: Design Course Distribution by Year and Program**

Striking differences between programs can be seen. Two have no design classes during the sophomore year. One has none during the junior year. Schools D and E seem to have very few design courses when compared to the other programs studied. School C's treatment of design is notable, with design curriculum content increasing over the four years, peaking in the senior year.

Similar analyses generated charts displaying design distributions based upon academic credits and percentage of total design units. We also looked at the distribution of classes that were “pure design,” having been identified on the course syllabi as 100% engineering design (as opposed to engineering science) versus classes that were a combination of engineering design and science. All of these analyses produced charts and tables that were, at first glance, similarly stimulating and compelling. However, on closer inspection, *all of them proved largely useless in our efforts to understand design education efforts across programs*. As we sought to make comparisons across courses and curricula, we came to the realization that *designation of courses as design was not consistent across schools. Indeed, it was often not consistent across courses within the same department*.

The quantitative analysis was, necessarily, driven by the belief that the units of analysis were equivalent. That is, design courses and, by association, design credits, were similar enough across classes and schools that comparisons based upon them would be valid. We found that this is not the case. As one example of this inconsistency, classes that, based upon the course descriptions offered in the course syllabi, were essentially the same could be labeled as design in one program and not another (see Figure 4).

	School A	School B	School C	School D	School E
<b>Select Common Courses</b>					
Dynamics	✓	✓	✓		
Solid Mechanics			✓		✓
Capstone Design/Senior Project	✓	✓	✓	✓	✓

**Figure 4: ABET Self-Report-based “Design” Designation of Select Courses**

The three classes presented here appeared on the Basic-Level Curriculum table for all of the five schools studied. The checkmarks identify which schools identified each class as a design class. No checkmark means the school identified the course as 100% engineering science.

For example, in only two of the five mechanical engineering programs examined, was *Solid Mechanics* designated a design course on BLC tables, whereas an examination of the course syllabi revealed that these courses were essentially equivalent (at least, as described in the syllabi). Indeed, the *only* course that was consistently labeled as a design course across all of the curricula examined was the Capstone Design Course. A partial explanation for this discrepancy can be found in the fact that, in School C, the syllabus declared that of the units offered for the course, only 0.25 were devoted to engineering design. The remainder was engineering science. If as little as 8% of a class’ content is design, we can begin to see why it might be easily labeled as having no design at all. This explanation reveals another challenge to our quantitative efforts. The ABET design checkmark designation says nothing about the proportion of a class’ content that is design. Our initial efforts operated under the assumption that classes designated as design represented substantial design exposure for the students. In these “partial design courses,” it might be difficult to identify exactly what portion of the content was actually design. An even greater concern is the degree to which these “bits” of design—as designated by individual professors—serve to create a complete design educational experience over the course of a student’s academic undergraduate career. Indeed, from our inspection of syllabi, we suspect that it may very well be that, for design education experiences, the sum of the parts may actually be *less* than the whole. It was observations such as these that motivated a second, qualitative phase of analysis.

The qualitative analysis was guided by a necessary rejection of the second assumption of the quantitative phase. During our qualitative analysis of the data, we set aside the assumption that design designations are equivalent, while maintaining that each designation is correct, based at the very least, upon the belief of the reporting instructor(s). Thus, our investigative challenge became the identification of the design in each class.

**Findings and Discussion: Qualitative Analysis**

This phase of the research was based in a detailed treatment of design course syllabi with the goal of identifying and describing the particular design content represented in each course with the design checkmark designation. The syllabus for each course was reviewed in its entirety with special attention given to (1) the course description, (2) course objectives or goals and (3) topics covered. Each idea presented in the syllabus, typically in the form of a sentence or bulleted point,



was examined and classified. On the first pass through the syllabi, classifications were generated as needed, with accurate description of content as the primary goal. This resulted in over 20 categories. A second pass resulted in consolidation and reduction of the categories into the four high-level classifications presented here.

Each classification is derived directly from information presented in the syllabi. While the design content of some courses could be completely described by a single classifier, there were also courses where multiple classifications were appropriate. As such, these classifications should be treated as traits and not exclusive categories. Each may specify what content and activity were *sufficient* to deem a course a design course. However, *any* combination of these classifications can be used to describe a single design class.

What follows is a description of each of the classifications along with representative syllabus excerpts.

### *Design as Experience*

The classification treats the most familiar variety of design course—the design experience course. The dominant and most familiar form in which design exists in the classroom is as design *experience*. In almost every program, this experience-based design appears in the capstone design course. Students typically work on open-ended projects in teams. Often these projects are for external clients, in order to increase the “reality” of the experience. There is an emphasis on approximating “real-world” engineering practice and approximating professional practice.

#### *Course Title:* Senior Project

*From the Syllabus:* To provide senior students an opportunity to acquire a working understanding of the principles of mechanical engineering through a capstone *design* project. The emphasis of the course is on guiding students in the design process while working in teams. To prepare the senior undergraduate student for the industrial work environment, to develop professional skills of the students, and to apply fundamental, basic scientific and engineering principles to a design that satisfies a need.

Another, increasingly common, design experience course is the introductory complement to the capstone design course: the cornerstone design course.<sup>5</sup> Such courses are typically offered to students early in their academic careers and serve to give student early exposure to design.

#### *Course Title:* Introduction to Mechanical Engineering

*From the Syllabus:* The purpose of this course is to introduce the student to the field of mechanical engineering through an exposition of its disciplines, including structural analysis, mechanism design, fluid flows, and thermal systems. By using principles and methods of analysis developed in lectures, students will complete projects in *design* and computer-aided engineering. These projects include conceptualization, analysis of candidate designs, and construction and testing of a prototype. The creative process will be encouraged throughout.

An interesting design experience course comes in the form of the capstone *analysis* course:

*Course Title:* Engineering Analysis

*From the Syllabus:* The purpose of this course is to develop in the student the professional method of solving engineering problems in analysis and *design*, through application of the fundamental principles of the engineering sciences. Because the course is built around actual engineering problems, it leans heavily on problem definition and modeling, for which assumptions based on engineering judgment must be made. Checking analytical results is emphasized, by use of dimensions, limiting cases, and reasonableness, since solutions are generally open-ended or not unique, and therefore must be technically defensible. Particular attention is paid to the interpretation, evaluation, and generalization of results, with dimensionless variables being used where appropriate.

In this course, design exists as "professional" problem solving--separate from the generation of a physical product or system. Here, what we may typically think of design, as it exists in capstone design courses is applied to an "analysis" task. That is, students must confront real-world problems and navigate the communication, interpersonal, and professional issues encountered in capstone courses, however, the primary tools employed by the student-designers are not design tools but analysis tools. In this example, we realize the limitations of the view that equates project based learning, teamwork, real-world problems, etc. with design. Indeed, we realize that design here is actually professional practice, whether it applies to "design" or "analysis" activity. We are led to make a distinction between design as an activity that produces a product and design as a way of thinking that is independent of the task to which this thinking skill is applied.

### *Design as the Technical*

The term technical is applied to courses that convey practical knowledge and skills, especially when such knowledge and skills are unique to the discipline. Examples of such courses frequently include those in Computer-Aided Design (CAD), Engineering Drawing, some forms of Manufacturing, and Finite-Element Analysis (FEA). All identified technical courses teach a practical engineering skill or tool set. Within our sample, two varieties of technical course can be identified. The first variety consists of subjects such as technical drawing and CAD where the focus is knowledge of the tool itself. Minimal effort, if any, is exerted in efforts to understand the theory underlying the tools. These tools are inherently useful, supporting the engineering process. Frequently these tools are those that support the various modes of engineering communication.

*Course Title:* Engineering Design Communication

*From the Syllabus:* "The communication of designs to manufacturing using basic definitions of points, lines and planes in space . . . Techniques from geometry, vector analysis and spatial definitions will be integrated to provide information to both the *design* and manufacturing processes."

The other variety of technical class identified may be more closely coupled to engineering science. Courses such as these present tools derived from relevant engineering theory. A prime example of this is FEA where the tools have evolved out of the need to augment engineering analysis. No matter how powerful FEA tools may be, it is still considered necessary for students

to be fluent in the engineering science principles that underlie the tool and that the computer potentially obviates.

*Course Title:* Computer-Aided Design

*From the Syllabus:* “To use computers in different stages of **design** with emphasis on the design representation, synthesis, and design analysis. . . To become familiar with the mathematical fundamentals of computer graphics. . . Finite Element Analysis (FEA), Continuum problems, Direct approach, Variational method and Ritz method”

Technical courses such as those treated above support the design process, enable the communication of design ideas and often involve design projects. However, the primary course emphases are on the acquisition of the technical skills embodied in the tools.

### *Design as Analysis*

Efforts at classification revealed many courses that are essentially engineering science courses, as exhibited by course description, lecture schedule, and course unit distribution that were assigned the design checkmark designation. These classes provide knowledge necessary for design, yet there is little explicit design content or activity. They appear to adhere to the notion that, in all engineering content, there must be *some* design. In these courses, it is unclear which course elements present design content or activity. One explanatory temptation is to conjecture that the design designation applied to these classes is motivated by the need to satisfy minimum design unit requirements as set by ABET. However, it is likely the case that this designation is, again, a reflection of yet another definition of design—one where design is inclusive of the theory necessary to support analytical and detailed phases of the design process.

*Course Title:* Vibration Analysis

*From the Syllabus:* “This course is designed to give students an understanding of the vibration of mechanical systems and how to use that understanding to control and **design** vibrating mechanical systems.”

*Course Title:* Introduction to Solid Mechanics

*From the Syllabus:* “Presents basic concepts of stress and strain of deformable bodies, state of stress and strain. Mohr's circle, and bending of prismatic bars, among other topics. This course is essentially a lecture course with very heavy emphasis on problem solving. The primary goal of this course is to provide a solid foundation upon which the student will develop competence in and an understanding of solid mechanics, particularly as it is needed for **design**.”

When, in these courses, the ratio of engineering science to engineering design content is presented, design typically makes up less than 25% of the declared class content.

Another case of “design as analysis” is the machine design class. Machine design classes typically involve little, if any project work. The design content is in the form of the theory necessary to select, specify and analyze machine components. In the average machine design course, engineering science and theory dominate and, though the goal may be a designed part or mechanism, the path to this product is typically much closer to typical engineering analysis tasks than it is to the less-constrained problems and methods typically encountered in design activity.

*Course Title:* Introduction to Design

*From the Syllabus:* “**Design** of machine parts by stress and deflection. Effects of fluctuating stresses and stress concentration. Design of shafts and other machine parts. Modern industrial design practice using standard components and design layout drawings.”

*Course Title:* Mechanical Design I

*From the Syllabus:* “To use the fundamentals learned in Statics and Solid Mechanics and the fundamentals learned in this course related to the variable loading in the **design** of selected mechanical elements and machines.

Even with the Machine Design course presented above, design is identified as only one of the course’s total three units. The remainder is engineering science. Similarly, in the case of the Heat Transfer course presented below, the only explicit mention of design speaks to what students *should* be able to do with the analytical content gained in the class.

*Course Title:* Heat Transfer

*From the Syllabus:* “This course presents the fundamental principles of heat transfer so students can solve problems typically encountered by practicing engineers. Oral exams consisting of concept questions provide students with the opportunity to learn to think on their feet. At the end of this course the student should be able to qualitatively describe the relevant physics of a given event involving heat or mass transfer. and will be able to use this knowledge to simplify the governing equations, if possible, and predict physically realizable outcomes using analytical, experimental, and numerical methods. The student should also be able to apply these principles to the **design** of thermal systems.”

This example course is interesting for a number of reasons. It is, admittedly an engineering science course. Only 0.25 out of 3.0 total credits assigned to this class are designated design—the remainder are engineering science. There is no mention of lectures on design practice or design process. That ~8% design content is found in the form of “concept questions” that encourage increased understanding of theory and the notion that “[t]he student should also be able to apply these principles to the design of thermal systems.”

### *Design as Pedagogy*

Beyond its importance as a body of knowledge to be studied and learned, design is also used to support other educational and institutional goals. This section identifies courses that exhibit these extended goals. Within many classes design is used as an instructional tool. It is the, oft implicit, intention of the instructor that engagement of a particular body of engineering theory by way of design will serve as a means of teaching that theory. The distinguishing factors of courses bearing this trait may be gleaned by understanding the primary learning goal of the classroom activity. In classes where the use of design may be considered pedagogical, design activity is used to promote more complete understanding of the subject matter and is secondary to this subject matter. An example of this subordination can be seen in engineering science courses where design projects are constrained to necessarily and substantially require the use of the specific engineering scientific theory that is the focus of the class. In such classes, design is used as a means to exposit theory.

*Course Title: Dynamics*

*From the Syllabus:*

*“The primary objective of this course is for students to understand and apply basic concepts of engineering dynamics. Specific skills include modeling, in which a concrete physical situation is described mathematically; graphical representations including free body and kinetic diagrams; solution of the equations of motion; and interpretation of the results of such analyses. The secondary objective is for students to **design**, construct and demonstrate a functional device that embraces certain concepts of dynamics.”*

Design is also used as a means to contextualize engineering learning and to motivate student interest in the field. Design courses serve institutional goals of exposure to the discipline, faculty and their research. It is also used as a means to excite, recruit and retain engineering students.

*Course Title: Introduction to Engineering*

*From the Syllabus:*

*“The purpose of this course is to introduce the student to the field of mechanical engineering through an exposition of its disciplines, including structural analysis, mechanism design, fluid flows, and thermal systems.”*

*“An introduction to the analysis, synthesis, design, and testing of mechanical systems, their components and instruments. . . To introduce students to mechanical **design**, mechanical engineering careers, and engineering practices.”*

This classification recognizes that design in the classroom may itself serve as the focus of educational efforts but may also serve other educational and institutional goals. Beyond enabling engineering design learning, design activity can support the learning of engineering science and also used as a vehicle for the realization of broader departmental and institutional goals.

Here it is useful to also acknowledge the fact that design as pedagogy may exist completely independent of design content. Indeed, there is a substantial and growing body of educational research and theory that addresses the use of design distinctly for its educational benefits, independent of subject and student age.<sup>6</sup>

## **Summary**

In this paper we propose four ways of classifying design as it exists in mechanical engineering design courses:

*Design as Experience*

*Design as the Technical*

*Design as Analysis*

*Design as Pedagogy*

By understanding the courses identified as design courses by their instructors, our goal is to understand the many and varied definitions presently in mind and in use in the academy. In doing this, we have begun to assemble a definition that, to the greatest degree possible, is a reflection of design education practice. Rather than declaring what design is or isn't, we seek to use this opportunity to reveal a definition that truly reflects design as it is taught.

The elements of this definition are offered as descriptors that can help to identify and specify engineering design education. They offer revealing perspectives on existing design classes and force a higher level of consideration of the nature of design in the classroom. They offer design educators a vehicle by which they may better design and structure individual courses. At the curricular level, one consequence of a limited definition of design is that though all of these different types of design may exist, they are treated in unknown proportions and at undefined times and locations. With this more detailed descriptive language to identify and describe design in the classroom, we offer a means of better knowing what we are teaching and also coordinating and assessing our engineering design education efforts.

As an example developmental and assessment potential of this language, we conclude by revisiting the course syllabus presented earlier herein (see Figure 5). In place of the single checkbox offered by ABET we have introduced multiple boxes suggested by the work presented here. This fictitious Basic-Level Curriculum table begins to suggest the types of description, course design and assessment we hope and seek to enable.

Beyond merely identifying the various flavors of design, the intention is that this classification will enable the incorporation of design into classes where it is traditionally absent and the broader distribution of design across the curriculum. We hope that it will enable a more detailed understanding of in which aspect of design students are actually engaged and allow instructors to identify opportunities for cooperation and collaboration that may have otherwise gone unrecognized.

**Table 1. Basic-Level Curriculum  
Mechanical Engineering**

Year; Semester or Quarter	Course (Department, Number, Title)	Category (Credit Hours)						
		Math & Basic Sciences	Engineering Topics Check if Contains Design				General Education.	Other
			Technical (✓)	Analysis (✓)	Experience (✓)	Pedagogy (✓)		
Freshman Fall								
	CIV		( )	( )	( )	5		
	Writing		( )	( )	( )	3-5		
	Math 41-Single Variable Calculus	5	( )	( )	( )			
	Physics 41-Mechanics	3	( ✓ )	( )	( )	( ✓ )		
Freshman Winter								
	CIV		( )	( )	( )	5		
	Writing		( )	( )	( )	3-5		
	Math 42-Single Variable Calculus	5	( )	( )	( )			
	Physics 43-Electricity	3	( )	( )	( )			
Freshman Spring								
	CIV		( )	( )	( )	5		
	Math 51-Linear Algebra & Differential Equations	5	( )	( )	( )			
	Physics 45-Magnetism	3	( )	( )	( )			
	E 14-Applied Mechanics		5	( )	( )	( ✓ )	( ✓ )	
Sophomore Fall								
	ME 101-Visual Thinking		3	( )	( ✓ )	( ✓ )	( ✓ )	
	E15-Dynamics		5	( ✓ )	( )	( )	( )	
	E155A- Differential Equations in Engineering <i>OR</i>	4	( )	( )	( )	( ✓ )		
	Math 52-Calculus of Several Variables	5	( )	( )	( )			
	E 40-Introductory Electronics		5	( )	( ✓ )	( )	( ✓ )	

**Figure 5: “Redesigned” ABET Basic-Level Curriculum Table (Excerpt)**

This figure presents an example of what a design in a curriculum *might* look like. As contrasted with the original BLC table from which it was modified, it represents an opportunity to better identify the design activity and content in each class and also begins to allow a better high level picture of design as it exists and is integrated across the curriculum.

## Future Work

The efforts at definition presented here will be expanded by revisiting the 20 classifications generated during the first phase of qualitative research with the intention of generating a final, more comprehensive set of classifications. For example, one class of engineering design insufficiently addressed in the discussion thus far is *Design as Thinking*.

With this more detailed classification schema, the quantitative analysis will also be revisited with the intention of producing results that are both compelling and valid. This will also allow an opportunity to contrast declared design education intentions, as described within the ABET self-reports, with the design educational practice as manifested in the actual curricula.

Beyond these near term goals, the work presented here is part of a larger, ongoing endeavor in which the fundamental and recurring question is “How do we effectively prepare engineering students to be professional designers?”

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## Bibliography

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<sup>1</sup> Cross, Nigel, “Designerly Ways of Knowing: Design Discipline Versus Design Science,” *Design Issues*, Vol.17, No. 3, 2001, pp. 49-55.

<sup>2</sup> <http://www.carnegiefoundation.org/PPP>

<sup>3</sup> Dym, C.L., Agogino, A.M., Eris, O., Frey D.D., Leifer, L.J., “Engineering Design Thinking, Teaching, and Learning,” *Journal of Engineering Education*, Vol. 94, January 2005, pp. 103-120.

<sup>4</sup> <http://www.abet.org/history.shtml>

<sup>5</sup> Dym, C.L., Sheppard, S.D., Wesner, J.W., ‘A Report on Mudd Design Workshop II: “Designing Design Education for the 21<sup>st</sup> Century’,” *Journal of Engineering Education*, Vol. 90, July 2001, pp. 291-294.

<sup>6</sup> Schwartz, D. L., Bransford, J. D., & Sears, D. L. (2005). “Efficiency and innovation in transfer.” In *J. Mestre (Ed.)*, Transfer of learning from a modern multidisciplinary perspective, pp.1-54.