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Engineering Design Educational Model: From Skills To Objectives

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ENGINEERING DESIGN EDUCATIONAL MODEL:
FROM SKILLS TO OBJECTIVES

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2010

Dedication

To my parents Beatriz Rangel Carrillo and Jose Gabriel Davila Gallegos.....
.....for teaching me to always exceed expectations.

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FROM SKILLS TO OBJECTIVES

by

JOSE GABRIEL DAVILA RANGEL, B.S.M.E.

THESIS

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Abstract

The objective of this thesis is to develop an engineering design educational pedagogy on how to improve the engineering design learning experience. The design engineering activity is a complex mix of skills and knowledge that has been taught over decades by directly delivering to the students the design methodologies developed by design researchers and by exposing the students to open ended projects that could develop their design skills. Understanding this we can conclude that the three main pedagogical components of a successful educational design experience are: the design skills, the design methods and the design projects. On one hand, the individual design skills must be properly developed in the student prior to the project experience, making it an overwhelming challenge. On the other hand the design methodologies can be difficult to implement didactically (i.e. teaching techniques), therefore the student struggles to learn, and even more importantly, to embrace such methodologies.

We present an approach to design engineering teaching through seven main steps: First, define the desired skills to be acquired by the student during the learning process. Second, from the vast world of design research, select the proper design theories and methodologies that fulfill all the previous requirements of skills. Third, organize the knowledge and skills to be acquired in complexity levels. Fourth, generate educational objectives for each of the knowledge and skills. Fifth, based on educational theories (teaching styles, learning styles, etc.), transform the design skills and methodologies to didactic tasks (lectures, problems, exams, etc.) in such a way that the student will be able to develop their skills and, learn and embrace such methodologies. Sixth, implement the tasks individually along the curriculum as close ended design experiences. Seventh, expose the student to open ended multidisciplinary senior design projects to integrate all the educational design experience components.

This model could serve initially as a diagnostic tool to characterize the current set of skills of a given design course or program. The model can also be used to implement educational tasks into the classroom and labs depending on the desired student profile.

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Chapter 1: Introduction

1.1 Overview

Engineering design is defined as a complex cognitive activity [11] in which the main objective is to change from a current to a desired status, through a planed and organized process that can involve multiple disciplines, social collaboration, open-ended problems, technical knowledge and advanced skills. The challenge of design educators is to nurture design skills and abilities in students to achieve the highest degree of competency. However, design methodologies can be pedagogically difficult to deliver, due to the disparate nature of design activities that are open ended, ill defined, multidisciplinary and can have social implications, causing struggles for the student to learn and develop design skills.

The objective of this thesis is to develop a pedagogical model to improve engineering design education experience by identifying a prescriptive relation between desired skills and specific educational objectives, which can be translated to didactical tasks to be performed by the teacher.

These is done by analyzing the skill to be acquired by the student, understanding the theories behind education, searching for state of the art in this field and developing a model. The thesis is composed of three parts, first a general background covering engineering design and education, followed by an analysis of the state of the art describing the current practices, and third, the development of a model to improve the engineering design educational process.

1.2 Motivation

The National Academy of Engineering stated in their report “The engineer of 2020: visions of engineering in the new century” [30] that: “Innovation will be our ticket to a vibrant healthy economy with a competitive edge, and the creation of large numbers of high quality jobs”. Also the College of Engineering at The University of Texas at El Paso (UTEP) states in its strategic plan that “Our nation’s future depends on its ability to be a global leader in innovation” as part of the core belief that “Diversity Drives Innovation”. [41] And design, within engineering field, is one of the key activities for successful product innovation.

1.2.1 Engineering Design

According to the National Science Foundation on its Strategic Plan for Engineering Design of 2004 [31], “Engineering Design is a socially-mediated, technical activity that creates and realizes products, systems, and services that respond to human need and social responsibilities.” From this statement it can be understood the important role of engineering design activities within the society since it is a major provider of commodities and its main function is to provide technical solutions to human needs.

1.2.2 Engineering Design Education

After acknowledging the relevance of the engineering design activity in the society it may seem obvious the importance of its proper teaching to the engineering students. What may not be so obvious is the complexity of such task due to design’s nature (open ended, ill structured, multidisciplinary, social activity) which is classified as one of the highest cognitive process of human intellect [25].

1.2.3 Engineering Design in Educational Philosophy and Programs

Historically speaking engineering design has typically been overlooked within engineering education: “The subject (of design) seems to occupy the top drawer of a Pandora’s box of controversial curriculum matters, a box often opened only as accreditation time approaches. Even ‘design’ faculty—those often segregated from ‘analysis’ faculty by the courses they teach—have trouble articulating this elusive creature called design” [17]. Although, in the last decade, only a few proposals have been presented which intend to address the importance of design within its philosophy or curricula. An example of such intent is Duderstadt’s “Engineering for a Changing World” [10] in which he classifies design as one of the essential skills for learning outcomes in a liberal undergraduate engineering curriculum and proposes a new paradigm for engineering education by mirroring the medical school training model in which the student learning is achieved through clinical practices.

Some of the biggest challenges within the engineering design education are related to the selection of the proper skills that the student should acquire before having a design experience and how to organize the teaching of those skills along the engineering program as seen in Figure 1.1.

A recent proposal of how to overcome these challenges has been presented by the MIT's Conceive-Design-Implement-Operate (CDIO) initiative [5], in which the authors propose a structured and detailed list of skills needed to develop any engineering profession as seen in Table 1.1.

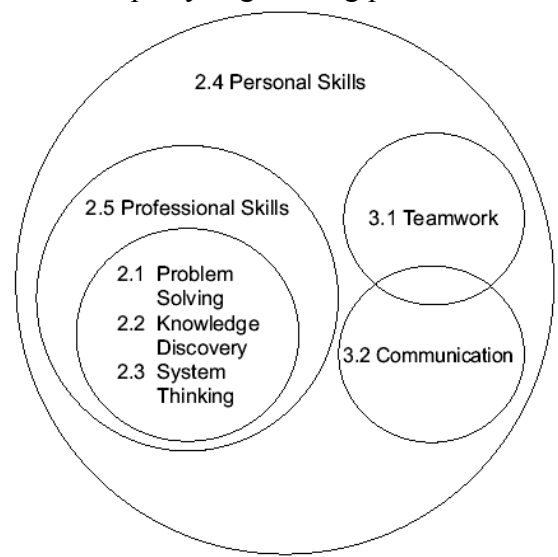


Figure 1.1: Venn diagram of personal, professional and interpersonal skills. [5]

This structure of skills was accomplished through the use of stakeholder focus groups comprised of engineering faculty, students, industry representatives and university committees. From this structure then they developed several levels of learning outcomes (see Figure 1.2) to come up with an integrated curriculum which can be applied to any engineering program (Table 1.1).

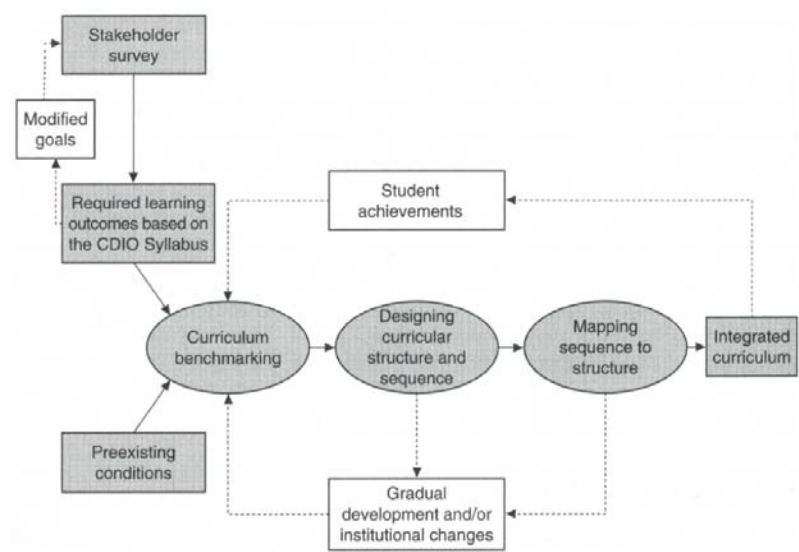


Figure 1.2: CDIO Integrated Curriculum Design Process Model [5]

Table 1.1: CDIO Integrated Curriculum for Engineering Programs [5]

1 TECHNICAL KNOWLEDGE AND REASONING	3.2 COMMUNICATIONS [g]
1.1 KNOWLEDGE OF UNDERLYING SCIENCES [a]	3.2.1 Communications Strategy
1.2 CORE ENGINEERING FUNDAMENTAL KNOWLEDGE [a]	3.2.2 Communications Structure
1.3 ADVANCED ENGINEERING FUNDAMENTAL KNOWLEDGE [k]	3.2.3 Written Communication
	3.2.4 Electronic/Multimedia Communication
	3.2.5 Graphical Communication
	3.2.6 Oral Presentation and Inter-Personal Communications
2 PERSONAL AND PROFESSIONAL SKILLS AND ATTRIBUTES	4 CONCEIVING, DESIGNING, IMPLEMENTING, AND OPERATING SYSTEMS IN THE ENTERPRISE AND SOCIETAL CONTEXT
2.1 ENGINEERING REASONING AND PROBLEM SOLVING [e]	4.1 EXTERNAL AND SOCIETAL CONTEXT [h]
2.1.1 Problem Identification and Formulation	4.1.1 Roles and Responsibility of Engineers
2.1.2 Modeling	4.1.2 The Impact of Engineering on Society
2.1.3 Estimation and Qualitative Analysis	4.1.3 Society's Regulation of Engineering
2.1.4 Analysis With Uncertainty	4.1.4 The Historical and Cultural Context
2.1.5 Solution and Recommendation	4.1.5 Contemporary Issues and Values [j]
2.2 EXPERIMENTATION AND KNOWLEDGE DISCOVERY [b]	4.1.6 Developing a Global Perspective
2.2.1 Hypothesis Formulation	4.2 ENTERPRISE AND BUSINESS CONTEXT
2.2.2 Survey of Print and Electronic Literature	4.2.1 Appreciating Different Enterprise Cultures
2.2.3 Experimental Inquiry	4.2.2 Enterprise Strategy, Goals, and Planning
2.2.4 Hypothesis Test, and Defense	4.2.3 Technical Entrepreneurship
2.3 SYSTEM THINKING	4.2.4 Working Successfully in Organizations
2.3.1 Thinking Holistically	4.3 CONCEIVING AND ENGINEERING SYSTEMS [c]
2.3.2 Emergence and Interactions in Systems	4.3.1 Setting System Goals and Requirements
2.3.3 Prioritization and Focus	4.3.2 Defining Function, Concept and Architecture
2.3.4 Trade-offs, Judgment and Balance in Resolution	4.3.3 Modeling of System and Insuring Goals Can Be Met
2.4 PERSONAL SKILLS AND ATTRIBUTES	4.3.4 Development Project Management
2.4.1 Initiative and Willingness to Take Risks	4.4 DESIGNING [c]
2.4.2 Perseverance and Flexibility	4.4.1 The Design Process
2.4.3 Creative Thinking	4.4.2 The Design Process Phasing and Approaches
2.4.4 Critical Thinking	4.4.3 Utilization of Knowledge in Design
2.4.5 Awareness of One's Personal Knowledge, Skills, and Attitudes	4.4.4 Disciplinary Design
2.4.6 Curiosity and Lifelong Learning [i]	4.4.5 Multidisciplinary Design
2.4.7 Time and Resource Management	4.4.6 Multi-Objective Design (DFX)
2.5 PROFESSIONAL SKILLS AND ATTITUDES	4.5 IMPLEMENTING [c]
2.5.1 Professional Ethics, Integrity, Responsibility, and Accountability [f]	4.5.1 Designing the Implementation Process
2.5.2 Professional Behavior	4.5.2 Hardware Manufacturing Process
2.5.3 Proactively Planning for One's Career	4.5.3 Software Implementing Process
2.5.4 Staying Current on World of Engineering	4.5.4 Hardware Software Integration
3 INTERPERSONAL SKILLS: TEAMWORK AND COMMUNICATION	4.5.5 Test, Verification, Validation, and Certification
3.1 TEAMWORK [d]	4.5.6 Implementation Management
3.1.1 Forming Effective Teams	4.6 OPERATING [c]
3.1.2 Team Operation	4.6.1 Designing and Optimizing Operations
3.1.3 Team Growth and Evolution	4.6.2 Training and Operations
3.1.4 Leadership	4.6.3 Supporting the System Lifecycle
3.1.5 Technical Teaming	4.6.4 System Improvement and Evolution
	4.6.5 Disposal and Life-End Issues
	4.6.6 Operations Management

This curriculum is designed to provide the proper skills and knowledge for different engineering career tracks depending on the combination of the generic and detailed skills as shown in Figure 1.3.

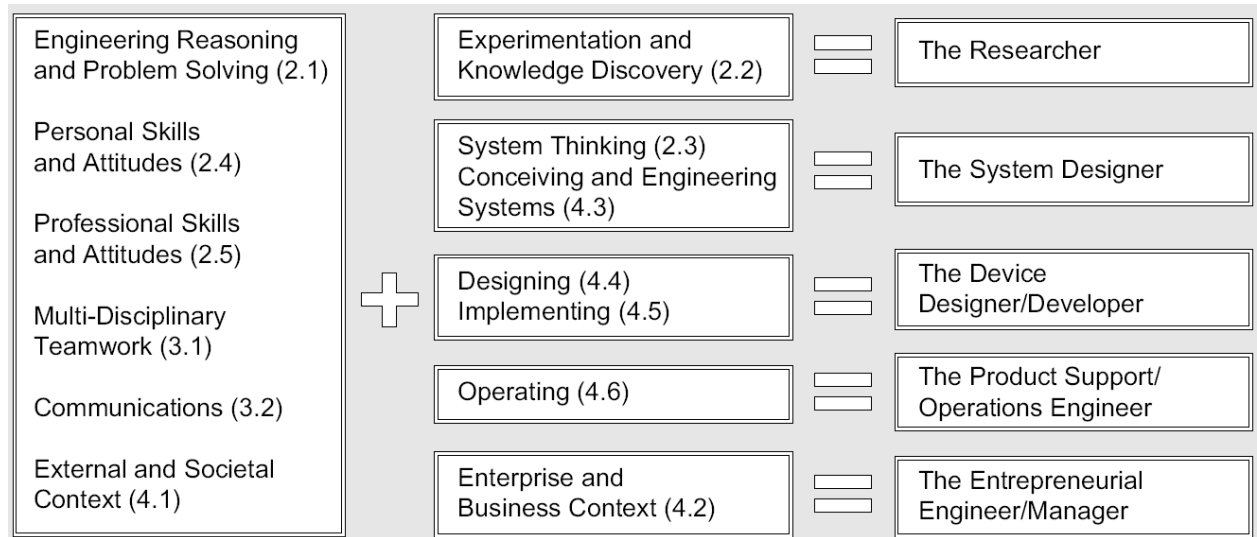


Figure 1.3: Professional Engineering Career Tracks using the CDIO Curriculum. [5]

It can be noticed that the design skills are part of the detailed skills of the CDIO classification and according to the authors, the detailed skills cannot be learned properly without covering all the generic skills previously, working as a vertical structure illustrated in Figure 1.4.

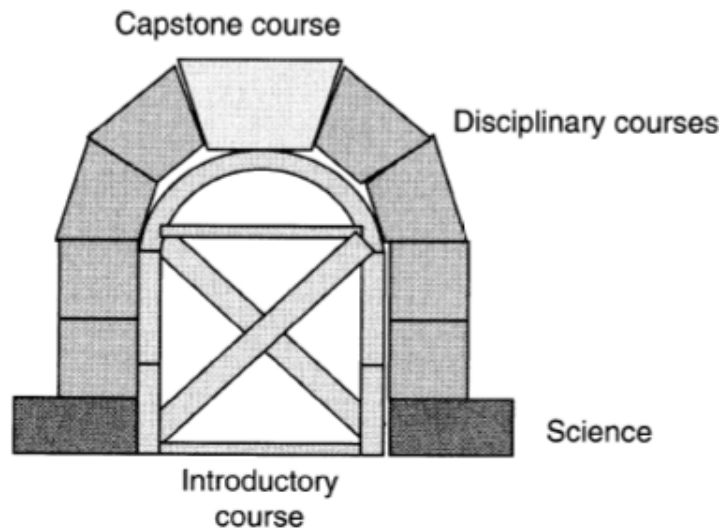


Figure 1.4: Metaphor of an Integrated Curriculum Structure. [5]

The CDIO proposal seems to cover many of the challenges that engineering design education faces in daily basis, even though this proposal only considers the pedagogical end of the educational spectrum, leaving open to the professor the application and execution of the teaching process (didactics).

Currently the College of Engineering at The University of Texas at El Paso (UTEP) is addressing the engineering design relevance by developing engineering programs that use as central support the design practice [34] and by constructing a state of the art engineering design studio (El Paso Innovation Center) in which the students can develop design skills through multidisciplinary, collaborative, industry related, real life projects in a clinical practice environment.

1.3 Research Objectives

- Develop an educational model that helps the engineering design professors on improving engineering design experiences of students.
- Support UTEP's College of Engineering Mission of: "Innovative educational programs that contribute to effective learning for our students, and that prepare graduates to be leaders and innovators in a variety of fields,"
- Identify engineering design skills.
- Understand the learning process of engineering students.
- Identify the difficulties and challenges of teaching and learning engineering design.

1.4 Research Approach

To achieve the objectives of this thesis a research approach was followed through search about engineering design education, teaching and learning theories, knowledge organization and educational assessment; analysis of the challenges within the current educational models in engineering design; and synthesis of the best solutions to integrate them in a single prescriptive model.

1.5 Research Scope

The objective of this thesis is not to develop all the details of the educational model rather than identifying the key milestones and variables to be addressed along the model. The main focus of this research is the methods to transform engineering design skills into educational objectives. Even though the proposed models may be applicable for areas different than design and even outside engineering, the available resources (time) allowed to explore this proposal only in the field of interest: engineering design.

1.6 Organization of this Document

The literature review in chapter 2 covers the background needed to understand the main topics that this thesis uses such as engineering design practice and research, educational models, teaching and learning theories and educational assessment. Chapter 3 covers the most relevant proposals on engineering design education. In chapter 4 the proposal and its development is fully presented along with an exemplification of its use in chapter 5. The validation of the proposed model is shown in chapter 6, followed by discussions, conclusions, original contributions and future work in chapter 7.

Chapter 2: Literature Review

2.1 Overview

The objective of this chapter is to present an overview of the main components of engineering design and education with their basic definitions and establish a common language along the thesis that will provide a framework for the development of the proposed model.

2.2 Engineering

The American Engineers' Council for Professional Development [30] has defined engineering as follows: “The creative application of scientific principles to design or develop structures, machines, apparatus, or manufacturing processes, or works utilizing them singly or in combination; or to construct or operate the same with full cognizance of their design...”

2.2.1 Engineering Design

Authors like Clive Dym and Patrick Little [12] state that: “...the word design is used both as a noun (n) and a verb (vb). “

- Design (n): a mental project or scheme in which means to an end are laid down; the arrangement of elements that go into human productions (as of art or machinery).
- Design (vb): to conceive and plan out in the mind; to devise for a specific function or end.

For these authors engineering design is: “a systematic, intelligent process in which designers generate, evaluate and specify designs for devices, systems or process whose form(s) and function(s) achieve clients’ objectives and users’ needs while satisfying a specified set of constraints.” “Designers are thus expected to describe the shape and configuration of a device (its organization), how that device does what it was intended to do (its function) and how the device (its inner environment) works (interfaces) within its operating (outer) environment.”

2.2.2 Engineering Design Model

The Research on Engineering Design could be simplified in five main Entities that interact in this activity:

- Designer
- Domain Knowledge
- Design Knowledge
- Problem to Solve (Need)
- Solution (Product)

This interaction is represented in the next flow model (Figure 2.1) where the arrows are links of information between the entities:

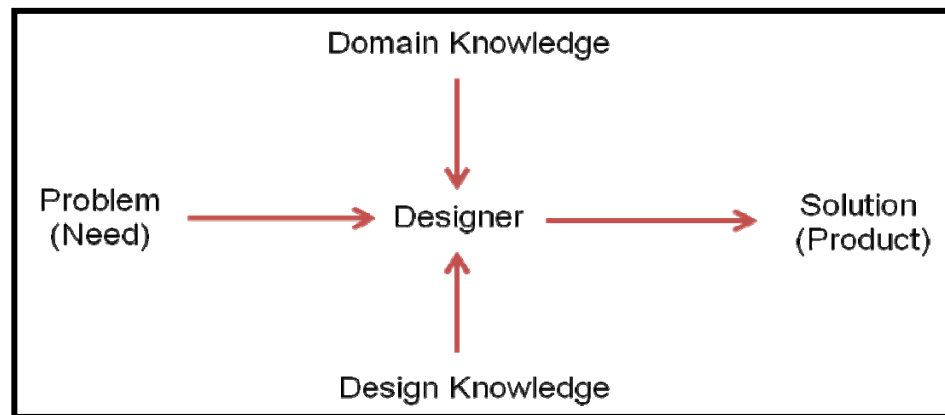


Figure 2.1: Engineering Design Entities Diagram

These are the definitions of each entity:

Designer: In our case refers to Design Engineers which “is a mediator between the philosopher and the working mechanic and like an interpreter between two foreigners, must understand the language of both, hence the absolute necessity of possessing both practical and theoretical knowledge.” [12]

Domain Knowledge: refers to the specific area of knowledge that surrounds the problem or the need to be solved. Example: A wheel chair requires knowledge of Engineering but also of Anatomy and Ergonomics.

Design Knowledge: refers to all the knowledge used by the Design Engineer to develop his design. Example: CAD (Computer Aided Design).

Problem (Need): is the circumstance that has the next components and characteristics according to G. Pahl and W. Beitz [33]:

Components:

- An undesirable initial state, i.e. the existence of an unsatisfactory situation.
- A desirable goal state, i.e. the realization of a satisfactory situation.
- Obstacles that prevent a transformation from the undesirable initial state to the desirable goal state at a particular point in time.

Characteristics:

- Complexity: many components are involved and these components, through links of different strength, influence each other.
- Uncertainty: not all requirements are known; not all criteria are established; the effect of a partial solution on the overall solution or on other partial solutions is not fully understood, or only emerges gradually. The difficulties become more pronounced if the characteristics of the problem area change with time.

It is also important to state that according to Dym and Little [12]:

- Design problems are ill structured because their solutions cannot normally be found by applying mathematical formulas or algorithms in a routine or structured way.
- Design problems are open-ended because they typically have several acceptable solutions.

Solution (Product): Is the device that meets the functions and requirements which fulfill the need or overcomes the obstacles of the initial problem to reach the desirable goal.

2.2.2.1 Engineering Design Knowledge

For the purpose of this research we define engineering design knowledge as all the information related to the engineering design topic that can be stored outside the human mind (e.g. literature, electronic data bases). The main focus of this research is on engineering design models and methodologies which are meant to guide and support engineers in their design activity.

2.2.2.2 Engineering Design Methods

Although there are various design process models [6], they all agree on a systematic sequence that varies in the number of steps but can be condensed in to four major phases:

Planning: the process of clarifying the task based on the next tools:

- Design Specifications: is the key document with the information obtained by the customer.
- Design Requirements: is the list of technical details that reflect the Design Specifications.

Conceptual Design: “Is the part of the design process where the basic solution is laid down through the elaboration of a solution principle.” And its main steps are:

- Identifying Functions: “Actions that the designed device or system is supposed to take or meant to do” (Dym and Little) [12].
- Generating Design Alternatives: Ideation Methods
- Combining Design Alternatives: Using Morphological Charts.
- Evaluating and Selecting Alternatives: Involving Decision Making.

Embodiment Design: to identify the preliminary layouts and form designs.

Detail Design: to optimize and communicate the final design.

2.2.2.3 Engineering Design Methods Classifications

Since there are dozens of design methods we will just mention some of their classifications that were collected from literature survey from several authors [6, 13, 14, 26, 32, 33, 40, 7]:

Engineering Design Methodologies Classifications:

Systemic (Pahl & Beitz, V.D.I.)

Integrative (Cross, Ullman, Kroes)

Prescriptive (Archer, Pahl & Beitz, V.D.I.)

Descriptive (French)

Driven by Problem/Solution (Crosss)

Driven by Information/Knowledge (Crosss)

Rational (Altshuller)

Creative

Adaptive/Innovative (Lopez-Mesa & Thompson)

Convergent/Divergent (Lopez-Mesa & Thompson)

Even though the diversity and variety of the methods we were able to find a common structure among all of them:

PRE-DESIGN	Need
DESIGN	Problem Definition
	Analysis
	Creation
	Synthesis
POST-DESIGN	Solution

Figure 2.2: Design Process meta-method.

We believe this could be understood as a generic method or meta-method which includes the main steps of the design process, based on the fundamental cognitive problem solving model, such that engineers could use as a base line to develop any kind of design activity.

2.2.3 Engineering Design Practice

To exemplify the different types of companies that offer design services we selected some of the most recognized design companies and describe them very briefly by answering the next questions: What is their Design Process? What are their capabilities? What is their experience? (see section A.2.1 in the appendix).

Since the world of design in industry is very wide and diverse, this research proposed classifications for the different types of design companies, to help us understand their interactions and roles in the society.

The classification is divided in five different characteristics: (see section A.2.2 in the appendix)

Dependency: Academy, Industry, Government, Military, Independent.

Clients: Academy, Industry, Government, Military, Independent

Collaboration with: Academy, Industry, Government, Military

Product Facet: Technical, Emotional, Business

Type of Service: Consultant (Design), Training (Knowledge), Independent Product Designer

For the purpose of our research we can summarize that the design practice in companies is mainly focal, this means that the organizations focuses in a specific type of client and product. Also it seems most of the cases they collaborate with only one type of institutions and give a single type of

service. Regarding the product facets, some of the companies that combine the three areas (technical, business and emotional) were influenced by the Design School of Stanford, mainly alumni of that university who created their own design company.

On the other hand, it seems that big corporations rely on independent design companies when it involves very specific area of knowledge or when it requires an integrated approach (technical, business and emotional) to create breakthrough designs, giving the idea that big corporations may only focus on what they already have experience and leave the unexplored to the design companies.

About their design process, it seems to be that most of them use the same systematic approach (Pahl and Beitz) [33] in conjunction with the basic and common creativity methods (brainstorming). There was no evidence of any kind of deviation or innovation in this sense in any of the companies. It can be notice one thing in common between all the companies: their purpose of improving the quality of life of people by designing and creating innovative products that fulfill their needs.

It is also important to mention that according to Maria Yang's survey [45] on the use of design methodologies in industry, researchers often think of how to make methodologies more useful to designers, but her finding suggest that when these designers do learn about a particular method, they generally find it useful rather than not useful, and that issues of training and education are key to making design methodologies gain acceptance, rather than improving them.

Overall there seems to be a disconnection between the design research and the design practice within engineering, since the industry doesn't seem to utilize the tools and models that the academia provides, and the academia doesn't seem to acknowledge the needs of the industry with regards to engineering design.

2.2.4 Engineering Design Skills

By definition a skill is a human capacity to perform a specific activity and is one of the competencies that education aims to develop in the student. One of the reasons for engineering design to be a complex activity is the need of many skills to carry it out.

It is important to acknowledge the vast and wide variety of skills required to perform engineering design. Table 2.1 shows in the next page a sample list of some of the skills related to engineering design,

identified by the industry as mandatory to perform successful product development, that were collected from literature survey.

Table 2.1: Engineering Design Skills Survey List

	Dym [12]	Eder [14]	Shah [35]	Ullman [40]	Pahl & Beitz [33]
Analytical thinking	X	X		X	X
Synthetic thinking	X				
Critical thinking		X			X
Divergent thinking	X		X	X	
Convergent thinking	X			X	X
Lateral thinking			X		
Visual thinking			X		
Imaginative thinking				X	
Qualitative reasoning	X		X		
Problem formulation	X	X	X		X
Problem solving	X	X		X	X
Creativity	X			X	
Decision making	X			X	X
Learning	X			X	
Organization	X	X		X	X
Prioritization				X	X
Time, project and resources control	X			X	X
Knowledge sharing, capitalization and management				X	
Team work	X			X	
Multidisciplinary collaboration	X			X	
Intercultural collaboration	X			X	
Written, oral and graphic communication	X	X			
Ethics	X	X		X	
Sketching	X		X	X	
Conceptual modeling	X			X	
Analytical modeling				X	
Computational modeling			X	X	
Prototyping	X	X		X	
Crafting		X			

As a summary it can be understood that the engineering design activity has a several different approaches (research and practice), done by many different players (academia, government, industry, etc), that combine multiple activities (planning, conceptualizing, etc) and require a wide variety of skills and knowledge to successfully accomplish it, making it one of the most complex challenges within the engineering profession.

2.3 Education

The main function of education is to improve the competency and capacity of the student through the acquisition of knowledge and the development of skills within a teaching-learning system. It is important to distinguish that teaching and learning are two different activities that relate to each other, though research and study of these two topics have historically grown in parallel paths which began to merge just a few decades ago. Therefore we need to be aware of the main theories of both topics individually.

2.3.1 Learning

Learning theories focus on how the learner acquires the knowledge mainly in a descriptive way. Even though these theories are diverse we could classify them in three main streams: constructive, behavioral and cognitive. The constructivism is based on the belief that learning only happens through own experienced endeavors. The behavioral approach to learning is based on measuring any kind of response for a given stimulus. And the cognitive theory comes from cognitive psychology, which objective is to model the human thinking process, including learning. To these theories we could also include “learning styles” of which there are several different models, but their purpose is to describe the acquiring knowledge preferences of the learner. [3, 24, 27, 36 and 39]

2.3.1.1 Styles

The origins of the learning styles theories came from the first studies about thinking styles which related the type of thinking to the hemisphericity domain of the brain (left or right). [36] In these researches it was found that the brain acts in a bi-functional mode balanced between both hemispheres and that people tend to use one of the hemispheres more than the other. Over time educators took these

findings and apply them in to the learning theories by suggesting that each person may be more attracted to a seatrain type of learning method than other types, evolving in to what it's known as learning styles. Many authors have proposed different learning styles theories, based on different theoretical background making the selection of the appropriate instrument a challenging task in which the educator [27] should define a selection criteria. Felder [19] summarized all the different theories in five dimensions shown in Figure 2.3.

<i>Preferred Learning Style</i>		
sensory	}	perception
intuitive		
visual	}	input
auditory		
inductive	}	organization
deductive		
active	}	processing
reflective		
sequential	}	understanding
global		

Figure 2.3: Domains of Learning Styles. [19]

Some of the most used learning styles instruments were done by: Myers, Kolb, Biggs, Reinter, Schroeder, Dunn, Dunn and Price. [24]

2.3.1.2 Cognitive Psychology

Cognitive learning theory comes from the cognitive psychology field, which purpose is to represent, through models, the process of human thought. This distinctive approach proposes that learning should be done by first making the learner conscious of his current thinking model (i.e. problem solving), and then showing him an optimal model in order for him to compare it. [3] According to Uljens [39], this learning theory increases the retention of thinking models in the learner due to the fact that the student is able to understand the fundamentals of such models and the reasons that makes it

optimal. Since design process methodologies are based on thinking models like problem solving, this learning theory may be a useful tool in our quest to improve engineering design education.

The main objective of these theories is to understand how the student learns either by recognizing his profile, environment, thinking process or own experience.

2.3.2 Teaching

Teaching theories focus on how the teacher delivers the knowledge to the learner mainly in a descriptive way. These theories are diverse, not standardized, empirical and essentially traditional based. Some of the most common teaching methods are: Constructivism, Direct Teaching, Direct Instruction, Teacher-centered and Student-centered. Each method is mainly determined by the nature of the subject matter to be taught, and also by the teacher's belief on how the students should be thought. [42]

2.3.2.2 Styles

The teaching styles refer to the manner of expressing the knowledge rather than the actual process of teaching (as the method). The same way learners have a distinctive preference of learning something, teachers also have a distinctive preference on how to teach something. The most common teaching styles are: [21]

- Lecturing

- Socratic

- Facilitation

- Experiential

- Practice based

- Problem based

- Resource based

- Mentoring

Felder [19] also summarized all the different teaching styles in five dimensions shown in Figure 2.4.

<i>Corresponding Teaching Style</i>		
concrete	}	content
abstract		
visual	}	presentation
verbal		
inductive	}	organization
deductive		
active	}	student participation
passive		
sequential	}	perspective
global		

Figure 2.4: Domains of Teaching Styles. [19]

2.3.2.3 Temperaments and Teaching

According to motivational theorists [27] there are four different temperaments that relate to Jungian learning styles theories based on the kind of motivation that drives the teacher to perform his or her duty: Traditionalist, Change Agent, Achiever & Free Spirit. These temperaments are defined by the own learning style of the teacher and each temperament has different relationships with each type of Jungian learning style, meaning that for a certain type of student, there is an optimum type of temperament.

Each of these theories have their own fundamentals and applications, all of them approaching the same activity from different points of view, providing a large variety of possible combinations for teaching scenarios.

2.3.3 Pedagogy & Didactics

From a strategic point of view, education can be divided into pedagogy and didactics. The first refers to the teaching/learning theory and strategy (how to teach?) and the second refers to teaching/learning tactics and methods (with what to teach?). Although there is not a clear limit defining where pedagogy ends and didactics starts, educational objectives are useful milestones to clarify the content of the classes (pedagogy) and suggest possible ways to teach such content (didactics).

2.3.3.1 Educational Taxonomies

Taxonomy is a classification which helps to identify and differentiate subjects based on their characteristics. One of the most influential taxonomies within the educational field is Bloom's "Taxonomy of Educational Objectives" [4]. Its cognitive domain is focused on the recognition of knowledge and the development of intellectual skills based on a constructivist model that organizes the knowledge by level of difficulty (see Figures 2.5 and 2.6), with the purpose of providing a framework for educators to set learning objectives in their classroom.

Learning Domains

Affective

Psychomotor

Cognitive

Intellectual Behaviors:

Knowledge (remember)

Comprehension (understand)

Application

Analysis

Synthesis (create)

Evaluation

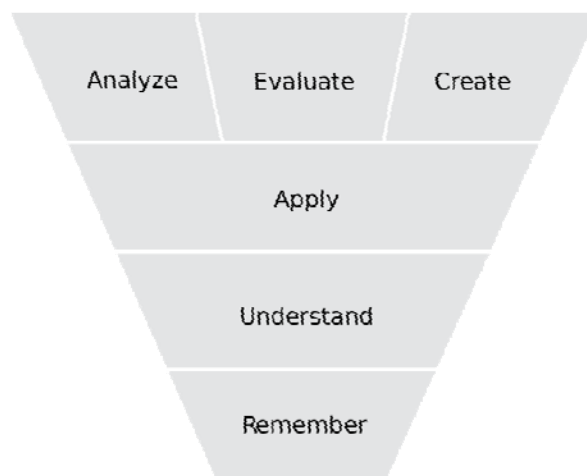


Figure 2.5: Bloom's Taxonomy of Educational Objectives Structure [4]

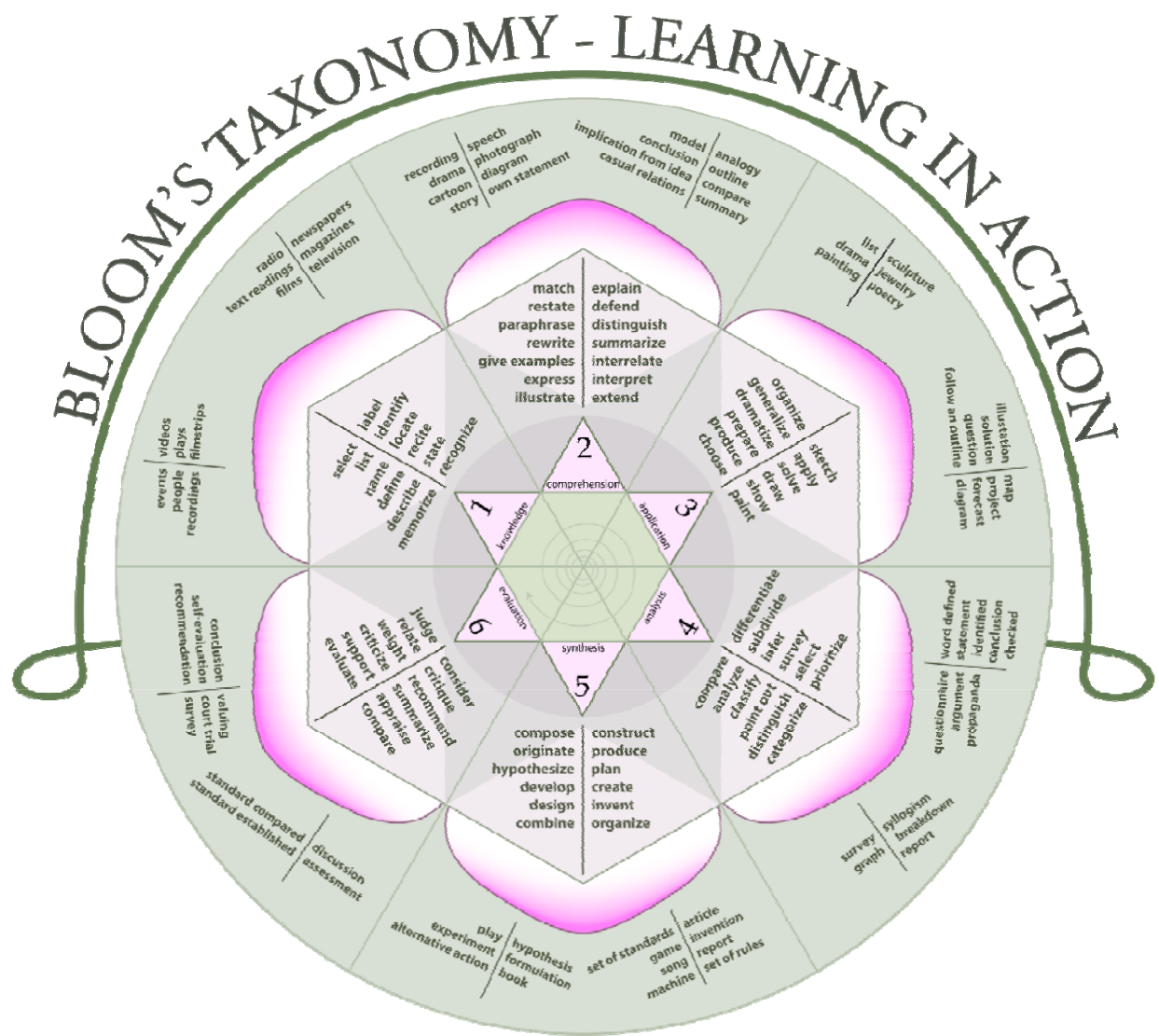


Figure 2.6: Bloom's Taxonomy of Educational Objectives Diagram [4]

Since then, many improvements and criticisms have been made to this document; a recent evolution of it is Marzano's "New Taxonomy" [29] who proposes a hierarchy model in terms of control and not in terms of complexity which has been proven by psychology researches to be only a temporary state on the learner upon the familiarity of the activity, this means that the new taxonomy is able to represent the learning activity as a duality of process and state, instead of only a state as Bloom proposed. Marzano's taxonomy is a two-dimensional model as represented in Figure 2.7. One of the axes consists of the hierarchy of "thinking systems" or levels of processing and on the other axis the "domains of knowledge".

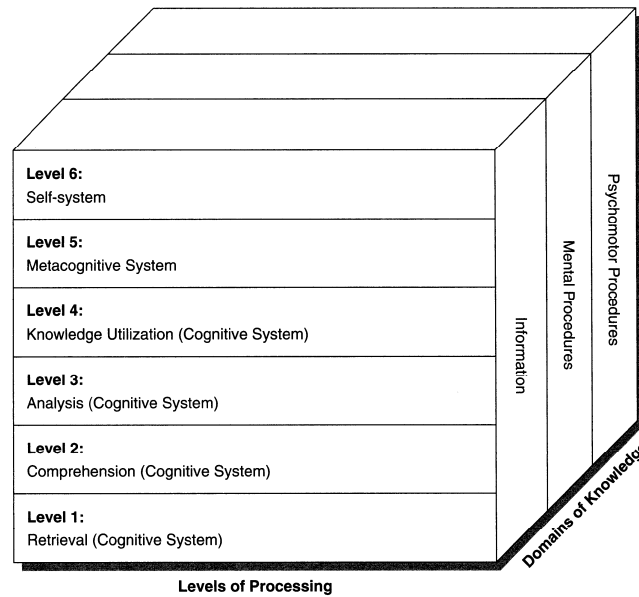


Figure 2.7: “The New Taxonomy of Educational Objectives” Model [29]

Marzano organizes the knowledge in three domains: information (declarative knowledge with no procedure involved: “the what”); mental procedure (procedural knowledge: “the how-to”); and psychomotor procedures (human body motion procedures). These domains are based on psychology research and each one is organized with their own hierarchies and categories as seen in Table 2.1.

The thinking systems hierarchy is built according to the author’s understanding of how the learning process happens in the human mind.

Table 2.2: Components of the Three “Knowledge Domains” [29]

Information	1. Organizing ideas	Principles Generalizations
	2. Details	Time sequences Facts Vocabulary terms
Mental Procedures	1. Processes	Macroprocedures
	2. Skills	Tactics Algorithms Single rules
Psychomotor Procedures	1. Processes	Complex combination procedures
	2. Skills	Simple combination procedures Foundational procedures

First, the learner faces a new task (new knowledge) to be acquired and makes a decision at the “self-system” level to engage or not to engage such knowledge. This level is ruled by the previous beliefs acquired by the learner in which his motivation will influence a decision depending on the perceived importance, the efficacy and the emotional response to such task. If the learner accepts to engage to it, he/she will set goals and strategies relative to the new task. This level is called “metacognitive system” and its main function is to control the lower level systems to achieve the defined goals. Finally, the “cognitive system” is the one that processes the knowledge through four levels: retrieval (obtaining and recognizing of information), comprehension (translation of knowledge into appropriate form for memory storage), analysis (generation of new knowledge based on reasoning activities) and knowledge utilization (synthesis of new knowledge based on reasoning activities)

Table 2.3: Levels of “Thinking Systems” [29]

Level 6: Self-System Thinking	Examining Importance Examining Efficacy Examining Emotional Response Examining Motivation
Level 5: Metacognition	Specifying Goals Process Monitoring Monitoring Clarity Monitoring Accuracy
Level 4: Knowledge Utilization	Decision Making Problem Solving Experimenting Investigating
Level 3: Analysis	Matching Classifying Analyzing Errors Generalizing Specifying
Level 2: Comprehension	Integrating Symbolizing
Level 1: Retrieval	Recognizing Recalling
	Executing

The cognitive and the metacognitive system are in constant interaction and iteration until the goal is accomplished generating new knowledge in the learners mind. These thinking systems are based on psychology research and each is organized with their own hierarchies as shown in Table 2.2.

This model intends to describe and decompose the process of thinking and the flow of information for any learning activity within the human mind; therefore this taxonomy allows the educator to set specific objectives for each stage of the learning process of the student for any kind of knowledge or skill to be acquired.

2.4 Engineering Education

According to Eder: “The aim of engineering education should be to achieve competency of graduates in analyzing and synthesizing technical products and technical systems.”[15]

A curriculum and teaching plan, should achieve the educational goals in a preplanned way through the choice of the educational material, and the teaching regulations. It should therefore define the subject matter, its volume, scope and detail, and its sequence. It should define relationships among the topics, and demonstrate these to students. Learning should be supported by a body of theory and by experience from practice. [14]

The current engineering educational system in the United States of America is an evolution of the french polytechnic and it is leaded by the Accreditation Board for Engineering and Technology (ABET) since 1932. [1] The ordinary curricular structure of the engineering programs is divided in two divisions, the lower division covers the common topics that are used bay all the engineering professions (mainly scientific knowledge) and the upper division focus on the particular subjects related to the major of the specific engineering program (mechanical, chemical, industrial, etc.). This structure is meant to promote and develop the proper skills and knowledge required in all the different applications of engineering (including design) to ensure the professional success of the students after they have accomplished an engineering degree.

2.5 Engineering Design Education

Based on the key research institutions and some scouting search it was selected some of the universities that are involved, in one way or another, with engineering design and describe them very

briefly by answering the next questions: What is their philosophy or approach to teach Design? Which are the classes or programs that they offer referent to Design? How are their key players in the institution? What kind of laboratories or research centers do they have? (see section A.2.3 in the appendix).

From the information previously gathered it can be concluded that each school seems to apply or approach the design teaching and design research in their own particular way, following different methods but all of them with the same objective: generate students that understand and apply a design process methodology with the purpose of creating products that address human needs.

The variety of the approaches of philosophies covers all the range from traditional engineering, through the artistic perspective and the business entrepreneurship. Only a few of them have an integral view that includes all of the mentioned.

One thing in common is that all of the schools have a strong relationship with the industry, by bringing projects to the institutions and providing services to the companies that accomplish two goals: “real life” learning experiences for the students and technological development through the academia.

About the relationship between design research and design teaching, there is no constant pattern; some are stronger in research, others in teaching and only a couple in both.

Chapter 3: State of the Art

3.1 Overview

Most of the available literature on engineering design education relates to descriptive experiences from engineering professors in capstone or senior design courses [37]. Few are prescriptive proposals of how to implement educational theories in engineering design activities.

3.2 Engineering Design Education Proposals

Here are some of the most relevant proposals in engineering design education pedagogies or didactics that were found in this research.

3.2.1 Eder's Pedagogy

As an example of these proposals Eder [15] presents (as pedagogy) a general model of curriculum for design engineering upon their needs of teaching: design science, technical systems, modeling and disciplinary information. They also present (as didactics) a general model of a transformation system, which can be applied to the educational system to transform the competencies of the learner, using pedagogical variables that define the overall components needed for the system (Figure 3.1). However they acknowledge that these proposals do not consider two key issues: How the students learn? and How to perform instructional methods for engineering design?

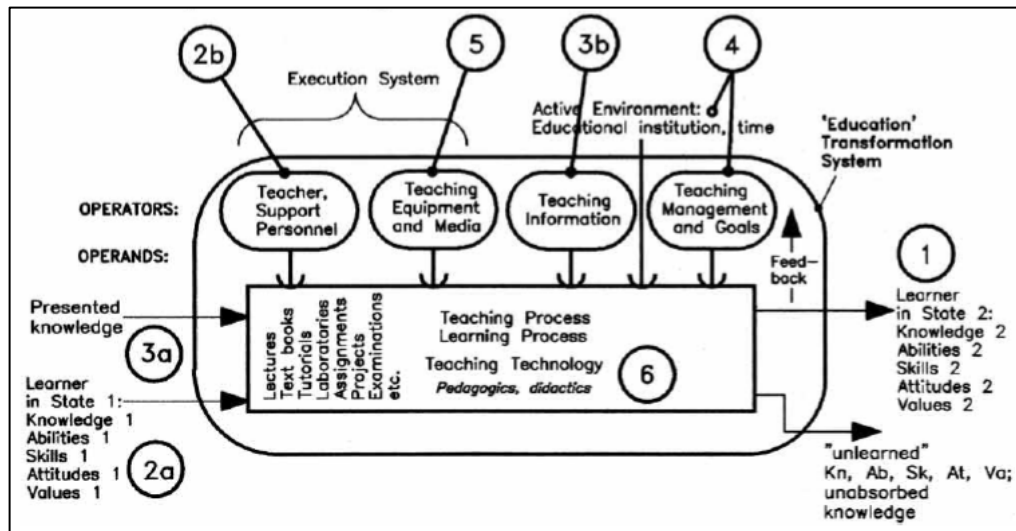


Figure 3.1: Educational Variables and Relationships to Educational Processes [14].

According to Eder the Teaching System is not different than a functional model where the transformation goal is to change the state of the student. “Students are the operand of the teaching and learning process, their peculiar feature is their active and reactive role (distinct from the reactive role of most operands in transformations), as living, thinking, and feeling humans with prior knowledge and experience.” [14] Since the Learner has a system on its own (psychostructure), we need to define in detail the way of implementing the “effects” on the transformation system based on the rules of Learning systems (push the correct buttons). Note: Teachers have their own psychostructure too.

Pedagogic Variables:

1. Goal of the Teaching/Learning System (Why?): “make learning possible”
2. Psychostructure (Who?):

*Learner - Prerequisite knowledge and personal, psychological, characteristics, possessed by a candidate for admission into the teaching/learning system should be defined.

*Teacher – Have suitable teaching methods and instruction methodology with an education in pedagogical matters. Make decision about the kind of teaching presentation (communication). Provide experiential and project-based learning (Figure 3.2), theoretical explanation & demonstration, use of didactic methods, and understanding their theories, must be exercised and practiced.

3. Subject matter (what?):
 - 1) contents,
 - 2) form of presentation of the learning materials and tasks
4. Social structure (where?): environment
5. Media (learning and teaching means) (with what? with what means?): objects, tools
6. Teaching method (teaching technology) (how, when?) procedures, strategies, tactics

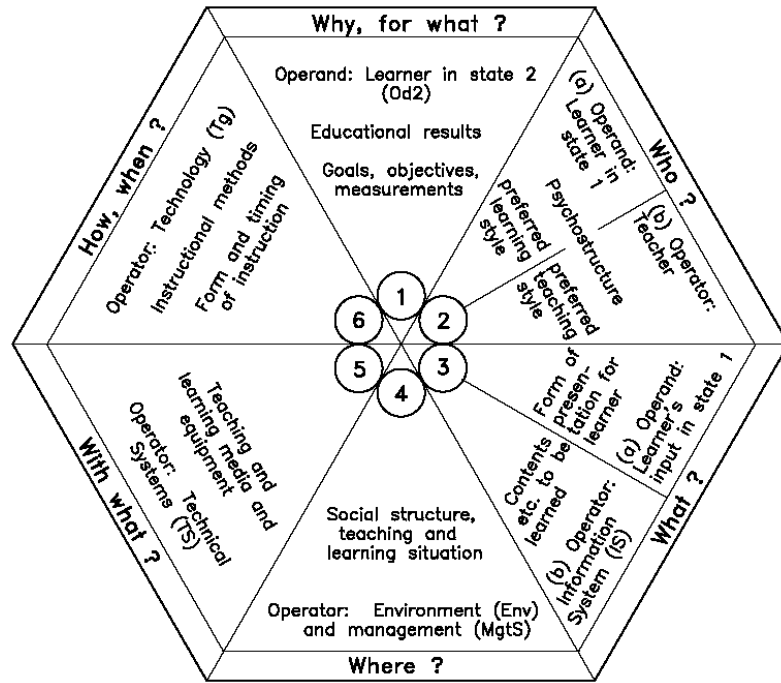


Figure 3.2 Eder's Educational Variables [14].

Eder also proposes that design courses should cover at least 15% of the total hours of engineering credits for each of the semester of the engineering program, distributing the content of the design courses in ten different but interrelated topics that should be learned in a parallel sequence rather than a serial sequence as seen in Figure 3.3.

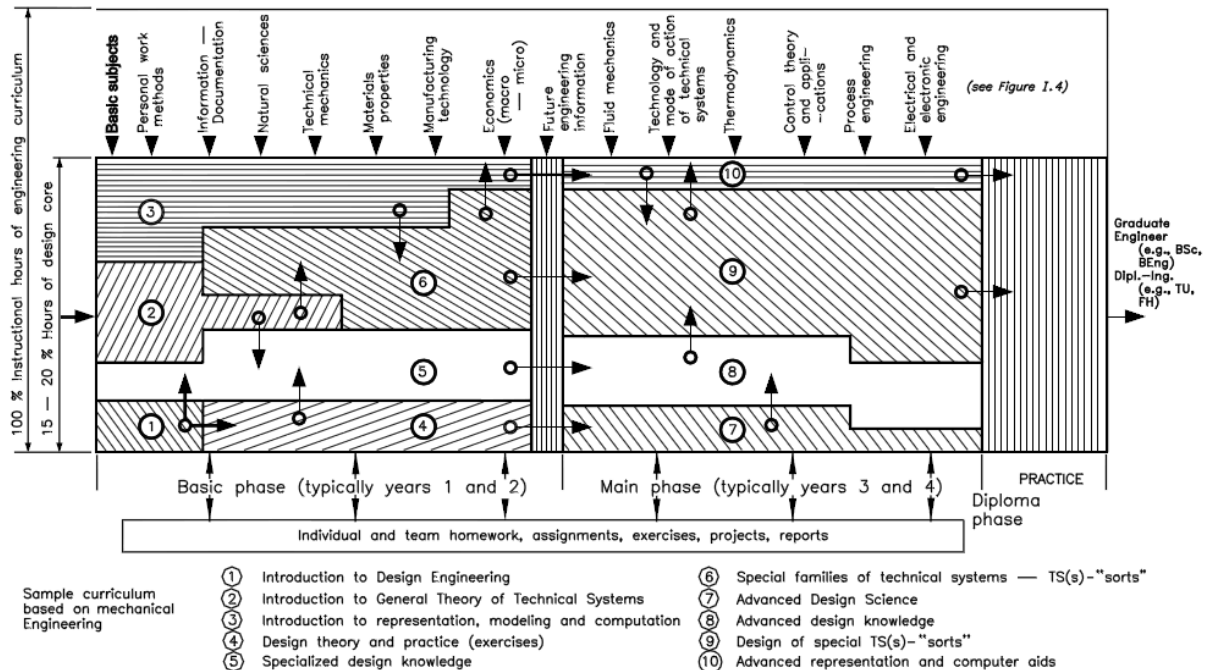


Figure 3.3: Eder's Curricular Structure [14].

3.2.2 Dixons's Courses

Another example of pedagogy is the work done by Dixon [8] who defines specific fundamentals to develop the design engineering intellectual process in students, based on industry's best practices for product realization, proposing specific courses that could shift the focus from teaching analytical design to cognitive design. Dixon analyzes some of the common mistakes done in engineering design education highlighting that proper learning may not be achieved by pure experience of a design project, rather than the correct experience, which should include the best design methods with the best teaching practices.

Table 3.1: Dixon's Engineering Design Education Topics [8].

Possible Organization of Fundamentals Into Courses	
Course Title	Fundamental Subject Content
1. Product Realization Processes in Business Organizations	Generic product realization process. Taxonomies of design, product development, and decision problem types. Types of business organizations. Introduction to marketing, management, finance, and personnel issues and concepts.
2. Manufacturing Processes	Basic physics and practical factors in the most prominent manufacturing processes; design for manufacturability, tolerance issues, and cost estimating for each process. Rapid physical prototyping methods.
3. Design of Mechanical Components	Parametric design and redesign of components employing optimization, Pahl and Beitz methodology, and dependency concepts. Configuration design of components. Conceptual design of components; Pugh's evaluation method. Cost estimating.
4. Design of Mechanical Assemblies	Assembly design. Assembly modeling. Design for assembly. Tolerance stack-up analysis.
5. Concurrent Multi-functional Team Design	Individual and group issues and principles for effective participation in multi-functional design teams.
6. Information Retrieval and Learning	How to find information about materials, processes, new methodologies, and technologies using libraries, computer searches, telephone inquiries, vendors, colleagues, consultants, and commercial registers. How to learn on one's own to employ new methodologies and technologies using textbooks, journals, colleagues, short courses, and technical meetings.

3.2.3 Dym's PBL

Other authors explored the recent didactic trend in engineering design education: problem based learning [11], in which they correlate the complexity of the design thinking process with this well accepted teaching style due to its closeness to real design practice. The authors acknowledge that this method has flaws, raising the question: how to better develop design thinking in the students? They believe that the answer resides in a main skill: divergent-convergent questioning.

3.2.4 Felder's Styles

An additional example of didactic exploration is the extensive work done by Felder with teaching and learning styles in engineering [19] providing a concise summary of most of the teaching and learning styles theories in five simple dimension shown in Figure 3.4.

<i>Preferred Learning Style</i>		<i>Corresponding Teaching Style</i>	
sensory	} perception	concrete	} content
intuitive		abstract	
visual	} input	visual	} presentation
auditory		verbal	
inductive	} organization	inductive	} organization
deductive		deductive	
active	} processing	active	} student participation
reflective		passive	
sequential	} understanding	sequential	} perspective
global		global	

Figure 3.4: Domains of Learning and Teaching Styles [19]

Unfortunately Felder does not provide the required depth for designing related activities, since his focus is to provide a general overview of the relationships between students learning and professors teaching styles along all engineering programs, concluding that there is a mismatch between the styles of both players (learner and teacher) leading to poor learning performance and high rates of teaching frustration.

3.3 Summary

From the above we can conclude that few pedagogical models have been developed for engineering design education, and even less models suggested by researchers in education have been applied in a prescriptive or systematic way, probably due to the design's complex nature, making the teaching-learning system a challenging task for this field.

Chapter 4: Model

4.1 Proposal

After exploring the existing educational proposals for engineering design it can be concluded that there is a disconnection between educational strategies (pedagogy) and educational methods (didactics) at least in a systematic and prescriptive manner. The transformation of the contents of engineering design curricula into educational tasks is not described by any of the previously mentioned authors, suggesting that the common practice of such transformation is left for the educator to perform under his/her own criteria and experience. Since one of the objectives of this document is to guide the design studio facilitator through the complete process of mentoring design students, and such facilitator may not have enough educational experience to perform such transformation on his/her own, a prescriptive model that performs such transformation must be proposed.

Such model must be able to:

1. Organize the engineering design knowledge in a logical and sequential way.
2. Transform the engineering design knowledge in to educational tasks.
3. Implement the engineering design educational tasks within the educational system.
4. Monitor the organization, transformation and implementation of the engineering design knowledge.

4.2 Development Strategy

To achieve the goals of the proposal a research approach was followed through search about knowledge organization, transformation, implementation and control methods; analysis of each of the available options for each stage of the proposal; and synthesis of the best solutions to integrate them in a single model.

4.3 Model Development

4.3.1 Organizing engineering design knowledge

The first objective was to find available skill organizations specifically for engineering design, few literatures were found relating this subject (mentioned in section 2.2.4) and only the CDIO proposal

[5] suggested a systematic method of how to organize such skills and knowledge. The next option was to find organizational tools that could lead us on how to create a logical and sequential hierarchy of engineering design skills and knowledge. The search would lead to the multiple taxonomies of knowledge starting from the well-known Taxonomy of Bloom [4], all the way to the most recent proposals of Krathwohl [25] and Marzano [29].

The next step was to analyze the characteristics of the main taxonomies to compare their strengths and weakness. Bloom's cognitive domain proposes a descriptive organization of six progressive levels that encompass the human intellectual activities: remember, understand, apply, analyze, synthesize and evaluate. This model proposes that human intellect depends on a structural construction of intellectual activities upon these six levels in which the higher levels activities cannot be properly done without the proper dominion of the lower levels.

Marzano's hierarchy [29] is based on the level of complexity of the procedural knowledge: single rule, algorithm (procedure with very specific outcomes and steps that do not vary), tactic (procedure with general rules but with no specific order) and macropcedure (operation involving many subprocedures with diversity of possible outcomes). Similar to Bloom's [4] this taxonomy is based in a structural construction in which the higher levels are supported on the lower ones. The rest of the taxonomies were disregarded since no major difference from these two main proposals was found.

Finally a decision was made to use Marzano's taxonomy [29] since its structure is more generic and is not based on specific intellectual activities rather than the complexity of such activities. Based on Marzano's definitions, an engineering design skills taxonomy could be created by relating the common characteristics of such skills and classifying them by types and levels of complexity.

4.3.2 Transforming engineering design knowledge in to educational tasks

At the strategy level of education (pedagogy) Eder [15] has developed models that include curricular structure on how to better teach design within engineering programs. But these models fell short at the tactics and implementation level of education (didactics) by acknowledging that these proposals do not consider two key issues: How the students learn? and How to perform instructional methods for engineering design? Similarly Dixon [8] analyzes the content of the engineering design

curriculum with respect to the needs of the industry and suggests specific courses that may fulfill those needs, but does not approach the methodology of how to teach such content.

At the methodology level of education (didactics) Dym et al [11] analyzes the success of problem based learning with engineering design, but also acknowledge that this method has flaws, raising the question of how to better develop design thinking in the students?

After finding these diverse points of view of engineering design education an analysis was done to understand the missing links along this transcendental transformation of engineering design knowledge into educational tasks. As seen in Figure 4.1 the link between pedagogy and didactics is a continuous and fading range where is hard to define a specific limit on when or where one finishes and the other starts. Along this range there could be established several milestones that go from the most generic and strategic, to the most applied and methodological of education: educational philosophy, curricula, courses, syllabus, educational objectives, tasks, teaching and learning methods. As the reader can notice, along the diagram, there are authors that have developed solutions or proposals for the engineering design education, excepting for two: educational objectives and educational tasks. These two important milestones along the engineering design educational path have not been previously addressed, to the knowledge of this author, and even more important a proposal that links the whole path between strategies and methodologies.

From this analysis it was understood that the challenge needed to be divided in two sections: how to transform engineering design knowledge in to educational objectives? and how to transform educational objectives into educational tasks?

Educational Taxonomies would help answering the first question. Marzano's [29] learning model describes that the knowledge which will be acquired by the learner goes through the six levels of thinking systems: self-system, metacognitive system, knowledge utilization, analysis, comprehension and retrieval. To achieve a successful learning process the learner should experience conscious learning activities at each level. Since the purpose of the educational objectives is to have a clear and well defined activity to be achieved at each learning stage of the student, such objectives are already defined

by Marzano as a template where the teacher only needs to “fill the blank” with the intended skill to be acquired by the learner.

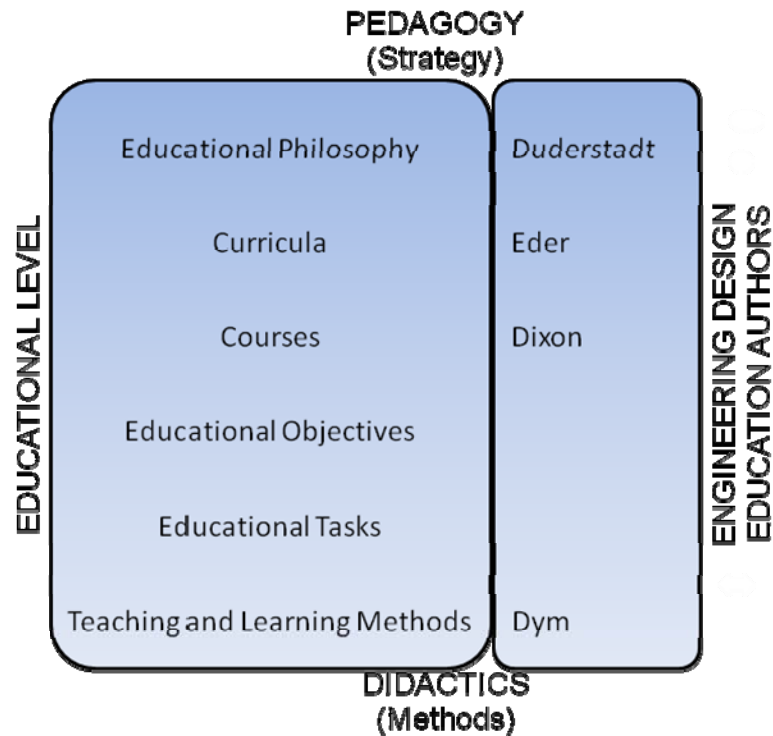


Figure 4.1: Engineering Design Educational Level-Author Diagram.

Even though, there was a missing link, how to connect engineering design skills or knowledge to the educational objectives taxonomies? At the moment of trying to apply an engineering design skill through Marzano’s taxonomy of educational objectives, it was discovered that any skill could be decomposed in to its function, strategy and process which later could be match to the three main levels of thinking systems: self-system, metacognitive system, knowledge utilization.

The answer to the second question: “how to transform educational objectives into educational tasks?” is not as simple as the previous ones, since it involves several variables: the teachers, the students and the learning environment. For each of these variables there are several theories and practices recommended by educational researchers. Teaching styles will help us to define what is the role of the teacher depending on the desired scenario (e.g. design studio, lecture classroom, workshop). Teaching temperaments will help us choose the optimal teacher profile that fits the engineering design activity. Learning styles will help us understand how the engineering students prefer to acquire the

knowledge. Cognitive learning can help us in the improvement and development of optimal thinking models (e.g. design process, problem solving, and critical thinking) of the learner.

4.3.3 Implementing the educational tasks in the educational process

Since no literature was available for engineering design educational tasks a quick analysis of the possible options of where or when along the educational levels (see Figure 4.1) the tasks could be implemented concluding in three options: along the whole curriculum embedded in the typical engineering courses of any program, within specific courses dedicated to engineering design or within engineering design experiences such as senior and capstone design projects.

4.3.4 Monitoring the educational process

A search was done on the common types of educational assessments finding four different kinds: assessment of educational systems, assessment of educational programs, assessment of educators and assessment of students. For each kind of assessment there are several proposals of how to maintain a feedback to the educational system in order to control its efficiency and quality. For the purpose of this research the type assessments that fit to our model would be to the educator (in this case the facilitator) and to the student.

4.4 Proposed Model

Four main steps were defined for the overall model: pedagogical organization, pedagogical transformation, didactic transformation and didactic implementation. The sequence of this model is a unique contribution of this author and the transformation steps make use of well accepted educational theories (e.g. Bloom, Marzano). Figure 4.2 presents the main steps of this educational model which will be reviewed in detail in the following subsections. As explained earlier, there are various skills for engineering design, but there is no clear or unique taxonomy. Assuming that a skill is selected, it is then decomposed following the proposed approach; obtaining with this a characterization of the skill. It is suggested as future work that this characterization be used to develop a taxonomy of engineering design skills. The decomposed skill is arranged according to Marzano's [29] levels of knowledge as a step to

define educational objectives. These educational objectives will be converted into educational tasks using Marzano's guidelines. [29]

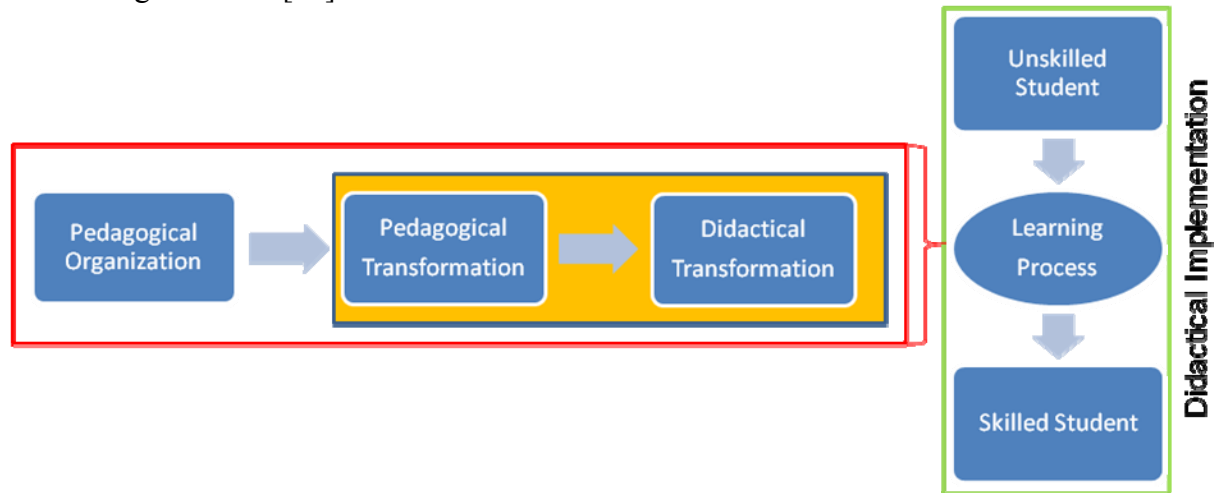


Figure 4.2: Engineering Design Educational Model Diagram.

4.4.1 Pedagogical Organization

The first goal is to identify and set the hierarchy or sequence of the skills to be taught (organize them) as shown in the first three steps of the Figure 4.3.

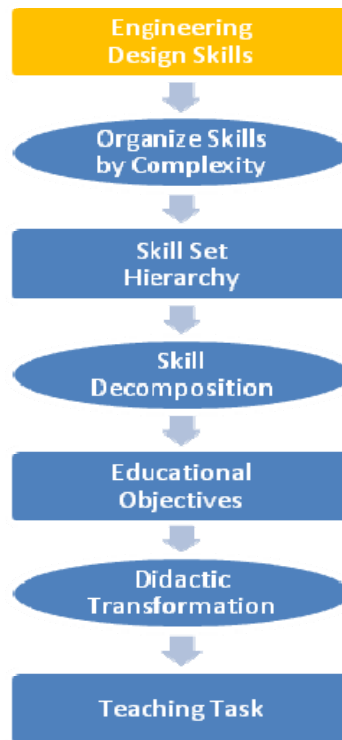


Figure 4.3: Skill to Teaching Task - Transformational Model Diagram.

4.4.1.1 Identification of Engineering Design Skills

The listing of all the engineering design skills is intended to help the teacher by decomposing the engineering design activity so each skill can be developed individually or in groups that simplify the learning process for the student, acknowledging that the main design skill is probably the integration of all the previous ones in a single activity: designing. Still there is a need to classify such skills in an orderly manner; here is where Marzano's taxonomy [29] could be applied.

4.4.1.2 Organization of the Engineering Design Skills by Complexity

A skill taxonomy for engineering design can be created based on Marzano's [29] domains of knowledge hierarchy and since designing is mainly an intellectual activity, the "Mental Procedures" domain, shown in Table 2.1, may be the best lead in this sense. The details of this organization are not the scope of this thesis and are considered for future work. However, since the mental procedures are constructively organized (the higher levels depend on the proper function of the lower levels) this classification (skill set hierarchy, see step three of Figure 4.3) would help the design educator to order the proper sequence in which the skills should be taught. Still the learning process of each individual skill has several stages that need to be addressed one by one.

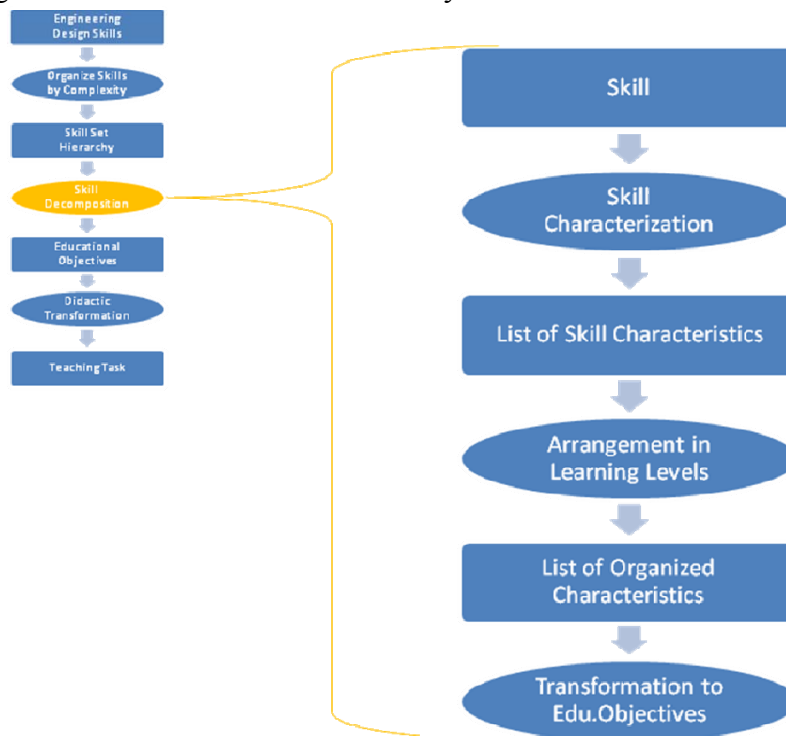


Figure 4.4: Skill to Educational Objective - Transformational Model Diagram.

4.4.2 Pedagogical Transformation

As shown in Figure 4.3 the transformation process of the skill to educational objectives is done at the fourth step called “Skill Decomposition” which is achieved through several sequential steps as shown in Figure 4.4.

4.4.2.1 Characterization of the Skill

After selecting the design skill the teacher must characterize it in detail in order to understand its purpose and the ways to accomplish it. This research proposes that any skill can be characterized by its function, its process and its effectiveness. The function lays out the exact objectives to be achieved. The process describes the steps required to attain such objectives and the order in which they must be executed. The effectiveness defines strategies and metrics that will monitor the quality of the results of such skill, serving as a control system that will give feedback to the teacher on the development of the skill in the student. After characterizing in detail the skill now it will be easier to set a teaching process that follows the natural learning process of the human mind by matching the corresponding level of thinking system to the skill characteristic.

4.4.2.2 Characterization Arrangement in Learning Levels

According to Marzano’s [29] learning model, to achieve a successful learning process the learner should experience conscious learning activities at each of the three levels of thinking systems: self-system, metacognitive system, knowledge utilization. Therefore the design educator first needs to identify which operators of each thinking systems match with which each skill characteristic. The function characteristic of the skill will be mainly matched to the self-system operators that focus on the importance to learn such skill. As shown in Table 4.1, the effectiveness characteristics will be mainly matched to the metacognitive system operators which focus on the strategies of how to learn effectively the skill. Finally the process characteristics will be mainly matched to the cognitive system operators that focus on the execution of learning. This arrangement of the skill characteristics helps the teacher to set the optimal teaching sequence of each characteristic and then set goals (educational objectives) to accomplish for each operator.

4.4.2.3 Transformation to Educational Objectives

The educational objectives are already defined as a template where the facilitator only needs to “fill the blank” with the intended skill to be acquired by the learner using Marzano’s “New Taxonomy of Educational Objectives” [29] as presented in Table 4.1.

Table 4.1: Engineering Design Educational Objectives for any Skill

<i>SKILL DECOMPOSITION</i>	MARZANO'S NEW TAXONOMY OF EDUCATIONAL OBJECTIVES		
<i>SKILL CHARACTERISTICS</i>	New Taxonomy Level	Operation	Educational Objectives for " _____ " skill
<i>SKILL FUNCTION</i>	Level 6: Self-System Thinking	Examining Importance	The student will be able to identify how important the mental procedure of _____ is to him and the reasoning underlying this perception.
		Examining Motivation	The student will be able to identify his or her overall level of motivation to improve competence or understanding relative to the mental procedure of _____ and the reasons for this level of motivation.
<i>SKILL EFFECTIVENESS</i>	Level 5: Metacognition	Specifying Goals	The student will be able to establish a goal relative to the mental procedure of _____ and a plan for accomplishing that goal.
		Process Monitoring	The student will be able to monitor progress toward the accomplishment of a specific goal relative to the mental procedure of _____.
<i>SKILL PROCESS</i>	Level 4: Knowledge Utilization	Decision Making	The student will be able to make decisions about the use of the mental procedure of _____.
		Problem Solving	The student will be able to solve problems about the mental procedure of _____.
	Level 3: Analysis	Classifying	The student will be able to identify superordinate and subordinate categories relative to the mental procedure of _____.
		Specifying	The student will be able to identify logical consequences of the mental procedure of _____.
	Level 2: Comprehension	Integrating	The student will be able to identify the basic structure of the mental procedure of _____ and the critical characteristics.
		Symbolizing	The student will be able to construct an accurate symbolic representation of the mental procedure of _____ differentiating critical and noncritical elements.
	Level 1: Retrieval	Recognizing	The student will be able to validate correct statements about features of the mental procedure of _____, but not necessarily understand the structure of the knowledge.

As one can see, the objectives may or may not use all the operations of each level of thinking system, making it a tailored method for each skill depending on the characteristics that match the operators. These objectives will guide the design educator in the creation of the task and its assessment upon the competencies obtained by the learner.

4.4.3 Didactic Transformation

The educational objectives are the requirements that the task must fulfill to achieve a successful educational process, but this objectives do not deal with the specific methodology of how to attain such requirements. Here is where the education theory can fill the blank by applying teaching theories and learning theories in the engineering design educational system which will help the facilitator develop the desired skill of the student through a specific didactical task. The details of this didactical transformation are not the scope of this thesis and are considered for future work. Although, the variables that may play a key role in this transformation have already been identified: teaching styles, teaching temperaments, learning styles and cognitive learning. These educational theories could lead the design educator on how to perform the educational task and achieve the educational objectives.

Chapter 5: Application Example

“Give a student a question to answer and she will learn the passage she has just read. Teach her how to ask questions, and she will learn how to learn for the rest of her life.” – James R. Gavelek & Taffy E. Raphael. [20]

As an example, one skill was selected to use the model and develop educational objectives. After selecting a specific skill or knowledge to be acquired by the learner, the model suggests to perform a pedagogical transformation followed by a didactical transformation and a didactical implementation. Since the scope of this thesis only details the pedagogical transformation, the chosen skill will go through the skill decomposition process to finally obtain its educational objectives.

The chosen skill to perform this exemplification was “questioning”. By questioning we mean the activity of asking questions or inquiring about a topic. According to Eris [17], question asking has a fundamental role in the thinking process of experienced designers. In his research he is able to demonstrate two main things: a correlation between designers questioning process and the outcome of their designs; and a unique set of design questions that were not classified by previous authors [8, 21] in the field of taxonomy of inquiries. Dym [11] also argues that the design thinking process is based in a “divergent-convergent questioning” dynamic, in which the inquiry plays an ignition role for the analysis and also for the synthesis (creativity) of any problem solving task.

From the educational point of view, Uljens [39] argues that inquiry is the starting mechanism for any learning process, and in the case of any research activity he correlates the learning of new things that no one else has known before (discovering), to the ability of inventing, by relating that both activities face the same challenge: generate new knowledge by asking and answering questions. From these we can conclude that the design process is an iterative learning process in which one of the cognitive tools to advance from one iteration to another is the ability to perform accurate questions.

5.1 “Questioning” Skill Characteristics

The first step is to characterize the skill of questioning in its function, its process and its effectiveness.

Questioning Function:

“Identify the lacking information between new knowledge and prior knowledge.” [44]

Questioning Process:

According to Dillon [8] the questioning process has six steps to the point of posing a question:

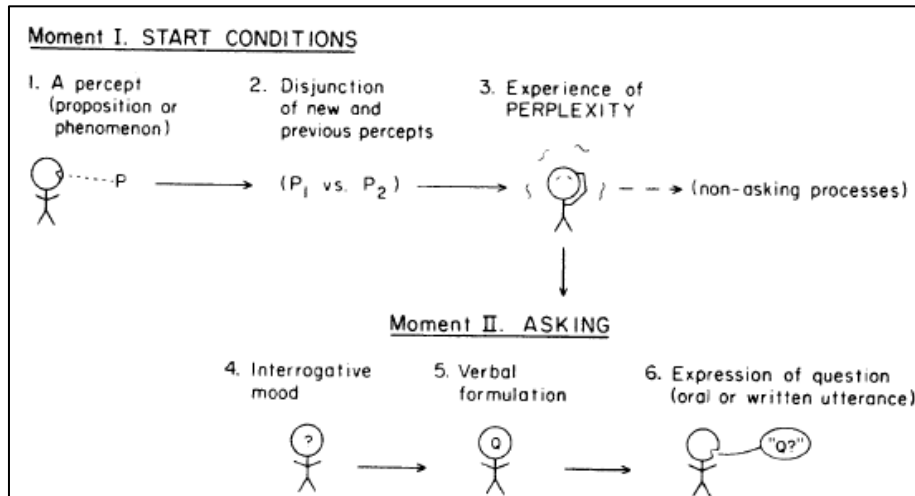


Figure 5.1: Dillon's Questioning Process. [8]

1. Perception (observation of a phenomena or new knowledge)
2. Disjunction (conscious differentiation between previous and new knowledge)
3. Perplexity (organismic experience of restlessness)
4. Conception (mental construction of the question)
5. Formulation (mental proposition of the question)
6. Verbalization (externalization of the question)

Questioning Effectiveness:

On strategies of how to generate questions effectively, Hunkins [22] proposes a holistic three steps approach by planning the possible questions related to the topic, implementing the chosen question to pursue and assessing the effectiveness of such question.

For the metrics that will monitor the effectiveness of the questioning, Walsh [42] summarizes some of the qualities of good questions which in a general description are the ones that move the human intellect beyond the obvious information.

Since both of these authors present a generic method or guidelines for monitoring the questioning process, it is needed to generate more specific metrics and strategies that guide the student through his skill development. The next metrics and strategy are examples of how the facilitator could monitor the effectiveness of question generation.

- Metrics (Effectiveness Graph; Figure 5.2):
 - Vertical Axis: Knowledge Level [4]
 - Horizontal Axis: Accuracy

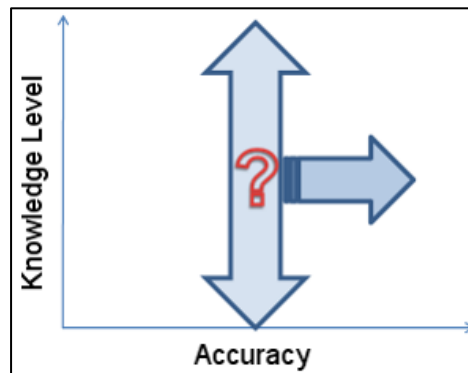


Figure 5.2: Questioning Effectiveness Graph.

The knowledge level axis uses the cognitive domain of Bloom's taxonomy [4] (knowledge, comprehension, application, analysis, synthesis and evaluation) as a metric to compare the different levels of cognition from the abstract concepts to the concrete facts which will guide the designer to cover all the different aspects related to its questioning. The accuracy axis is defined by the concept of comparing two or more questions and then decide which ones do a better job in: facilitating the understanding of previous knowledge and new knowledge, in facilitating the answering strategy and facilitating the answering execution. This means that the accuracy is a comparative measurement between several options and such comparison is based on the needs and circumstances that surround the question. The effectiveness strategy, as shown in Figure 5.2 is for the designer to improve the accuracy at each iteration and to visit all knowledge levels as necessary.

- Strategy:
 - 1-Generate a question.
 - 2-Locate the question in the Effectiveness Graph.

3-Decide in which direction to evolve the question.

4-Decide how to evolve the question.

5-Repeat the steps until a satisfactory question has been reached.

This strategy is indented to make the questioner conscious of the level of knowledge of the proposed question and how much does the question facilitates the process of acquiring new knowledge. At the moment of deciding in which direction to evolve the question is suggested that the questioner will enhance his knowledge on the subject by covering all the levels of knowledge. To decide on how to evolve the question is by finding the words that facilitate: the understanding, the answering strategy and the answering execution.

An historical example [38] of how to evolve the question in its accuracy is Leonardo da Vinci's pursue to design a flying machine. His first sets of designs were based on answering the next question: "How to overcome nature's forces?" referring specifically to gravity force. The proposals to solve this question surrounded the flapping mechanism that never convinced Leonardo. Some years later he changed his original question: "How to utilize nature's forces?" referring to the phenomena of aerodynamics. The next proposals guide him to design what we now call "gliders". Both questions are equally valid, but for the technological resources that Leonardo had at that time, the glider was a more feasible solution than any lifting machine. The reader may notice that for any chosen skill to be developed, its characteristics may not be previously detailed by other authors, forcing the facilitator to analyze and synthesize such characteristics on his own.

5.2 "Questioning" Skill Characteristics Arrangement

Based on the skill characterization and analyzing each taxonomy level operation, Table 5.1 shows the skill characteristics arranged by Marzano's taxonomy levels. [29]

5.3 "Questioning" Skill Educational Objectives

With the proper matching of characteristics and operators now it is simpler to "fill the blank" of Marzano's [28] educational objectives template as seen in Table 5.1.

Table 5.1: Questioning Skill Decomposition and Educational Objectives.

SKILL DECOMPOSITION		MARZANO'S NEW TAXONOMY OF EDUCATIONAL OBJECTIVES		
	Questioning Characteristic.	New Taxonomy Level	Operation	Educational Objectives for "Questioning" skill
QUESTIONING	Design and Problem Solving application of Effective Questioning.	Level 6: Self-System Thinking	Examining Importance	The student will be able to identify how important the mental procedure of <u>questioning</u> is to him or her and the reasoning underlying this perception.
	Benefit / Cost relationship of Effective Questioning.		Examining Efficacy	The student will be able to identify beliefs about his or her ability to improve competence or understanding relative to the mental procedure of <u>questioning</u> and the reasoning underlying this perception.
	Possible achievements due to Effective Questioning.		Examining Motivation	The student will be able to identify his or her overall level of motivation to improve competence or understanding relative to the mental procedure of <u>questioning</u> and the reasons for this level of motivation.
	Effective Questions.		Specifying Goals	The student will be able to establish a goal relative to the mental procedure of <u>questioning</u> and a plan for accomplishing that goal: "Develop the skill of evolving questions in the most effective manner."
	Question Evolution Strategy	Level 5: Metacognition	Process Monitoring	The student will be able to monitor progress toward the accomplishment of a specific goal relative to the mental procedure of <u>questioning</u> .
	Evaluate the evolution of the question until satisfactory result.		Monitoring Accuracy	The student will be able to determine the extent to which he or she is accurate about the mental procedure of <u>questioning</u> .
	Where to evolve the Question.	Level 4: Knowledge Utilization	Decision Making	The student will be able to make decisions about the use of the mental procedure of <u>questioning</u> .
	How to evolve the questions.		Problem Solving	The student will be able to solve problems about the mental procedure of questioning and will be able to use the mental procedure of <u>questioning</u> to solve problems.
	Application of questions in Problem Solving.			
	Disjunction phase of questions.	Level 3: Analysis	Matching	The student will be able to identify important similarities and differences relative to the mental procedure of <u>questioning</u> .

Effectiveness Dimensions: Accuracy level, Knowledge Level and Types of questions.		Classifying	The student will be able to identify superordinate and subordinate categories relative to the mental procedure of <u>questioning</u> .
Questions Process.	Level 2: Comprehension	Integrating	The student will be able to identify the basic structure of the mental procedure of <u>questioning</u> and the critical as opposed to noncritical characteristics.
Perception, Conception and Formulation of questions.	Level 1: Retrieval	Executing	The student will be able to perform a procedure without significant error, but not necessarily understand how and why the procedure works.

Table 5.1 (Continue): Questioning Skill Decomposition and Educational Objectives.

Since this transformational method is generic for any skill, the model could have several different applications within engineering design: capstone design courses, topics of design related classes, intensive training for design experiences (within UTEP's design studio), etc.

Chapter 6: Validation

Since the scope of this thesis was to analyze the current state of engineering design education and create a generic model that connects from the pedagogies to the didactics, the validation of the proposed model will be based on comparing the chosen educational tools (e.g. Taxonomy of Educational Objectives) to other available tools that perform the same educational function.

From the four main phases of the proposed model (Pedagogical Organization, Pedagogical Transformation, Didactical Transformation and Didactical Implementation) the main focus of this thesis is on the Pedagogical Transformation, therefore it is needed to validate its two stages of transformation (Skill Characterization and Transformation to Educational Objectives).

6.1 Validation of Skill Characterization

The skill characterization in to its function, process and effectiveness it is an original contribution of this research, and no other characterization or decomposition of skills was found within the literature available to this author. Therefore, there is no available educational tool that could help validate this part of the proposal.

6.1 Validation of the Transformation of Educational Objectives

For the creation of educational objectives this research chose Marzano's "New Taxonomy" [29] among more than twenty other taxonomies. To validate this tool a brief description and a pro/con analysis of each of the available options is presented in Table 6.1. From this summary we can conclude that Marzano's [29] is the most complete taxonomy since it has a robust proposal to classify the different levels of knowledge and has a proven structure of learning process. From the rest of the taxonomies Krathwohl [25] is the other one that presents a learning process, but does not consider any motivational milestone within such process and the hierarchy of knowledge is a continuation of Bloom's [4] which is based on empirical education.

Table 6.1: Analysis of Educational Objective Taxonomies.

AUTHOR TAXONOMY	BRIEF DESCRIPTION	PROS	CONS
MARZANO [29]	Levels of Knowledge and process of learning.	Considers both Level of Knowledge and Sequence of Learning Classification of knowledge in different levels. Levels of knowledge based on complexity. Motivational (self-system) stage of learning. Process of learning.	Lowest levels of knowledge based on empirical education.
KRATHWOHL [25]	Levels of Knowledge and process of learning.	Classification of knowledge in different levels (based on Bloom's). Process of learning.	No motivational (self-system) stage of learning. Levels of knowledge based on empirical education.
BLOOM [4]	Levels of Knowledge.	Classification of knowledge in different levels.	No learning process. No metacognition or monitoring of learning process. Levels of knowledge based on empirical education.
STAHL [25]	Information Acquisition Flow, mainly focused on the perception, retention and organization of the acquired knowledge.	Simplified assessment process for the educator.	No hierarchy or levels of knowledge. No metacognition or monitoring of learning process. No analysis or synthesis stages.
ROMIZOWSKI [25]	Levels of Knowledge and Skill performance (reproductive and productive)	Classification of knowledge (based on Bloom's) Classification of skill (similar to Krathwohl's). Skill performance process.	No learning process. Levels of knowledge based on empirical education.
BIGG [25]	Knowledge acquisition and process (growth of thinking).	Process of knowledge construction.	No hierarchy or levels of knowledge. No learning process. No metacognition or monitoring of learning process.

Chapter 7: Discussion & Conclusion

This thesis presents a model to transform engineering design skills into design tasks with a focus on the decomposition of skills and their transformation into educational objectives. Overall, the approaches presented here make use of well-known educational theories such as Bloom's [4] and Marzano's [29] in combination with original contributions such as skill characterization and the overall model integration.

7.1 Model Application

Although this model is intended for a specific application within UTEP's design studio, it can be discussed other possible applications of this same model at different levels of the engineering educational system.

7.1.1 Engineering Design Crash Course

Now that this model allows us to transform any design skill in to detailed educational milestones, the next step would be to identify the most important set of design skills that any successful design engineer should have, apply the proposed model to each of these skills and combine all of the resultant tasks in a single course. This way the students that would need to go through a design experience within the design studio and may not previously had experience or knowledge related to design, would be more prepared to confront his/her design project. Though it is important to remember that any skill by definition requires practice, therefore, such course should be focus on meeting the educational objectives of each skill characteristic, through practical and hands on experience in a reduced amount of time, to accelerate the process of learning.

7.1.2 Inside Projects

When the student is already embedded in a design project, he/she may need a specific type of skill or knowledge to overcome a challenge. Since the role of the facilitator is not be an expert on any single kind of design skill or knowledge, but rather, a generic mentor, the facilitator could use the proposed model to transform the requested specific knowledge in to educational tasks that would guide the student in the proper direction of learning such skill.

7.1.4 Along the Curriculum

The ideal process would be to first distribute and implement the engineering design tasks individually along the curriculum as close ended design experiences in such a way that the student would gain practice within the lower and upper division courses, and then expose the student to open ended multidisciplinary senior design projects to integrate all the educational design experience components. The CDIO proposal [5] and Eder's Curricula Structure [14] could serve as a reference of which skills should be thought and in which order they should be thought to have a sequential and integrated curriculum that improves the engineering design learning experience of the students.

7.2 Findings & Challenges that were overcome

This thesis presented a brief analysis of the challenges within engineering design education by understanding the gap between pedagogy and didactics within the design teaching/learning system. Also we mentioned some of the available tools for education, exploring the theories of taxonomy of educational objectives. And finally proposed a possible solution to this challenge, by utilizing those tools.

7.3 Concluding Remarks

“The designer is a professional learner” – Dr. Noe Vargas

Many of the authors that have been cited in this thesis agree in one thing, there is a strong linkage between design and learning. The engineering design activity within the professional field requires lifelong learning skills, since every single innovative product needs the integration of multiple disciplines and diverse skills, it cannot be expected that the designer comes prepared from college with all these knowledge on his mind. What it could or should be expected is that those designers must be prepared to keep learning as much as it is needed for as long as it is needed.

7.4 Original Contributions

The main contributions of this research can be separated in three parts:

1. Linkage or transition stages between educational milestones (e.g. from educational philosophy to curricula through the proposed engineering design skill organization).
2. Decomposition of skills for its use in educational objectives.

3. Integration of all the educational levels through a prescriptive, sequential and systematic model.

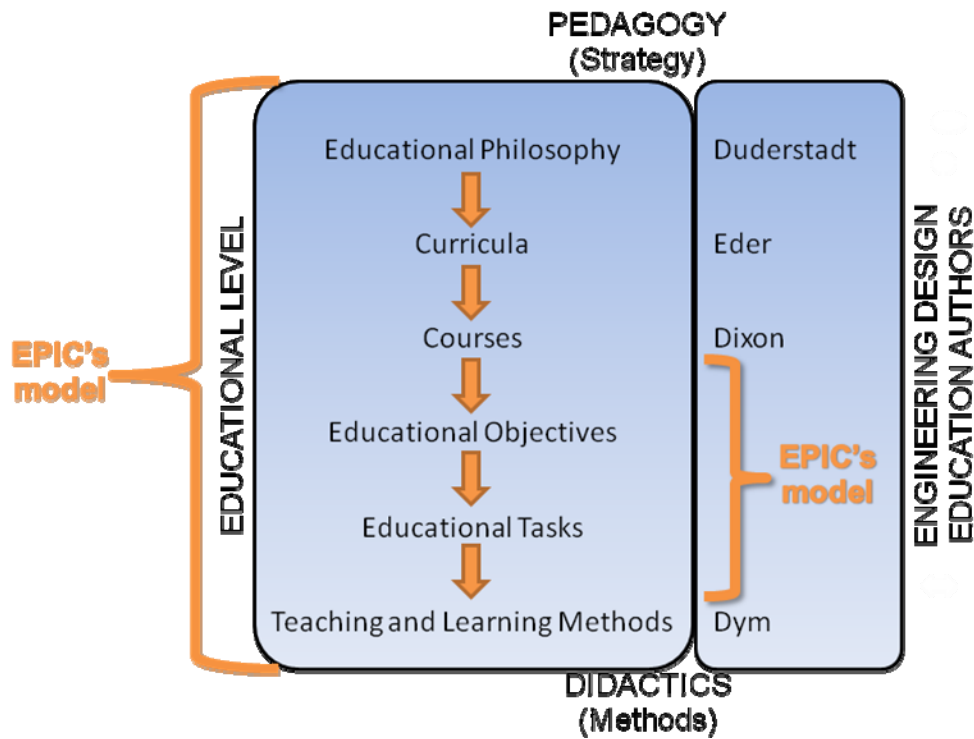


Figure 7.1: Engineering Design Educational Level-Author Diagram - Contributions

7.5 Future Work

Future work will focus on skill organization and didactic transformation of educational objectives into educational tasks, the tasks prior and subsequent to the focus of this thesis. Also, on the validation of the model, the application to other engineering design skills, and the generalization of the model to be used in other areas outside of engineering design.

7.5.1 Engineering Design Skill Organization (Taxonomy)

As mentioned previously, a taxonomy of design skills is needed in order to set a proper sequence of the skills to be learned. Some guidance to this challenge could be found on Marzano's [29] hierarchy of mental procedures, since he proposes a structure of this mental activities based on their complexity in a constructive sequence (see section 2.3.3.1). Also the skill characterization can be of use since it

decomposes the functions and process of the skill, a classification of those skills could be based on common types of functions and processes.

7.5.2 Engineering Design Skill Selection

Based on the engineering design skill taxonomy a group of skills could be identified as the most fundamental (structurally speaking) for the construction of the rest of the design skills, and build a basic design course that integrates the proper tasks that could develop those fundamental design skills.

7.5.3 Didactic Transformation

The transition between educational objectives and educational tasks is a challenging one, since the didactics (educational methods) need to consider several variables: the engineering teacher, the engineering student, the learning environment and the knowledge or skill to be acquired. As mentioned in the literature review, there are several theories and practices for both teaching and learning methods, and then the question is: which ones to use for engineering design skills? The answer may be in finding the linkage or dependency between the variables, for instance it is important to consider that the learner profile is not a variable that the educational system can control; therefore the other two players (teacher and environment) need to be adapted to the first one. This may be the biggest challenge of the skill-task model.

It is recommended that the current template of educational objectives should be used to relate the level of learning to the educational task as Marzano [29] suggests. And then add columns that mention the type of teaching and learning theory that should be recommended to be used as seen in Table 9.1.

Table 7.1: Engineering Design Educational Task for Knowledge Sharing Skill

New Taxonomy Level	Operation	Tasks for "Knowledge sharing" skill	Teaching Theory	Learning Theory
Level 6: Self-System Thinking	Examining Importance	Ask the students to work individually in an engineering design problem (pump selection for a piping system) providing each with a piece of information. Then Ask the students to share their information with other students.	Experiential	Cognitivism

The reader may notice that there could be multiple combinations to build the skill-task path, giving freedom to the user to adapt the model to their circumstances, without ignoring that these educational tools are focused on three players, the teacher, the learner and their environment.

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Appendix

A.1.1 Education inside the Engineering Design Studio at UTEP

El Paso Innovation Center (EPIC) will be an engineering college-wide resource for students to work on multidisciplinary collaborative real-life projects. It will provide state of the art facilities, tools, hardware, software, and most importantly, knowledge to facilitate the design process. The main objective is to develop specific design skills on students through project-based hands-on experiences. Students participating will come from all departments in the college, and even from other colleges (business, arts) as needed by the project. Many of those students may come from senior design courses. Projects may come from different sources: industry, research labs, design competitions, and entrepreneurs with ideas. Careful selection of projects is necessary. Teams will be composed of students, mentors from related departments and from industry, and supported by EPIC's facilitators and project managers. EPIC will provide support at the multidisciplinary collaborative level, complementing the great work that each department does in teaching disciplinary design.

A.1.1.1 EPIC's Main Objectives

- Provide engineering students with hands-on experience in multidisciplinary and collaborative product design and realization.
- Improve the overall multidisciplinary design skills of our engineering students.
- Promote multidisciplinary design collaboration (inside and outside the College of Engineering).

A.1.1.2 EPIC's Main Guidelines

- EPIC promotes multidisciplinary and collaborative hands-on student involvement.
- EPIC brings students, faculty, and industry to work together in projects.
- EPIC is a multidisciplinary collaboration "sandbox" for students.
- EPIC complements and collaborates with existing labs and resources in CoE and UTEP.
- EPIC extends as a network of resources.
- EPIC focuses on collaboration and integration while departmental senior design labs focus on disciplinary design process.

(For detail guidelines of the design studio, see section A.1.3 in the appendix).

A.1.1.3 EPIC's Main Function

The overall function of EPIC is to provide and improve design experiences of engineering students by facilitating multidisciplinary interaction through design education, entrepreneurship and high quality product development.

EPIC's functions may be divided in two main focuses: product development and designer development as seen in Figure A.1.

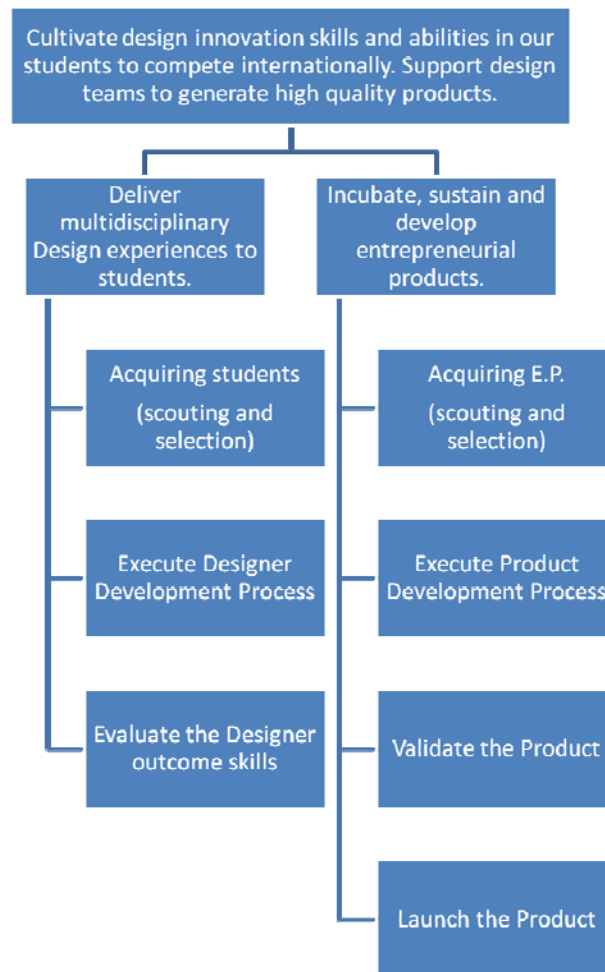


Figure A.1: EPIC's Functional Decomposition

(For detail functions of the design studio, see section A.1.5).

A.1.1.4 EPIC's Organization

The organization of the design studio is based on its two main focuses: the design student and the product to be designed (see Figure A.2). The design programs branch will focus on the successful development of the projects that arrive at EPIC. The design studio branch will focus on giving all types of support to the people that uses EPIC and the administrative branch will focus on the sustainability of EPIC. Each of the activities defined on Figure A.2 are necessary for the design studio to function properly and accomplish its objectives, but one of the key activities of this organization relies on the “Facilitator”. According to Peter Jarvis: “Facilitation literally means ‘easing’. Its art is in drawing out the wisdom already embedded and lying dormant in the psyche of the learner.” [23]

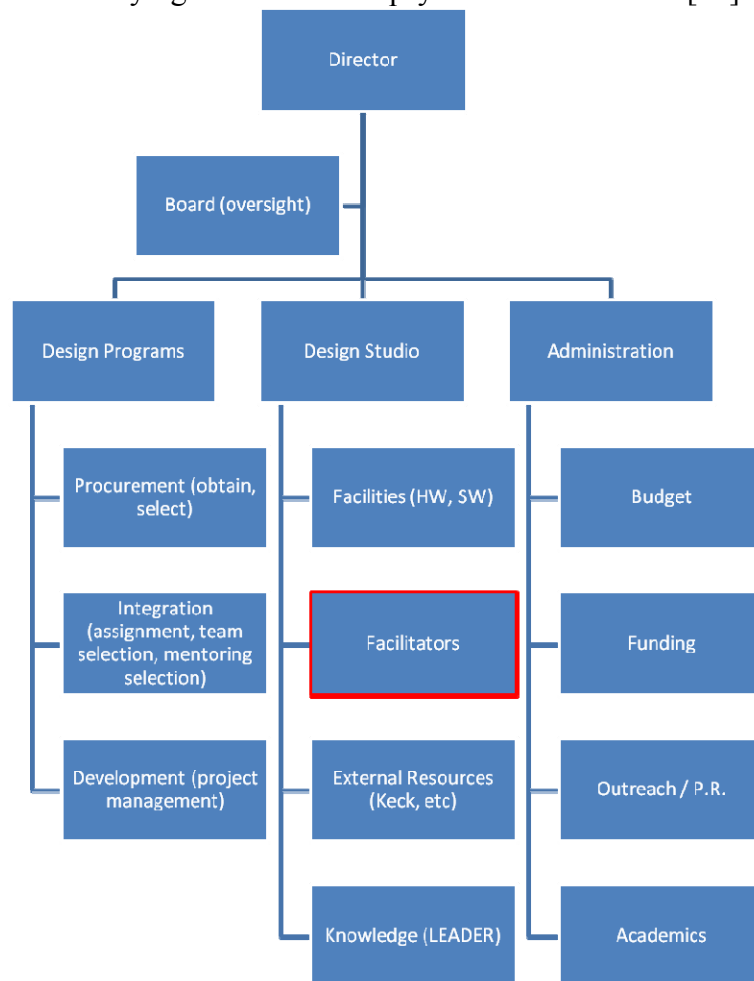


Figure A.2: EPIC's Organizational Chart.

The function of the facilitator within this organization is to guide the student through his own learning process. Since the design activity requires multidisciplinary knowledge, it would require several

mentors from each discipline to help the student acquire the proper knowledge for his product development. Instead, the facilitator will help the design student on learning on his/her own, the required knowledge to develop his project, decreasing the amount of resources needed to support the project and developing lifelong learning abilities in the student.

As seen in Figure A.3, the facilitator will need two kinds of skills and knowledge in order to provide the proper guidance to the students: design and education. Since the profile of the facilitator may or may not be a previously instructed educator, and may or may not be an experienced designer, formal training and guidance of how to do their job is needed.

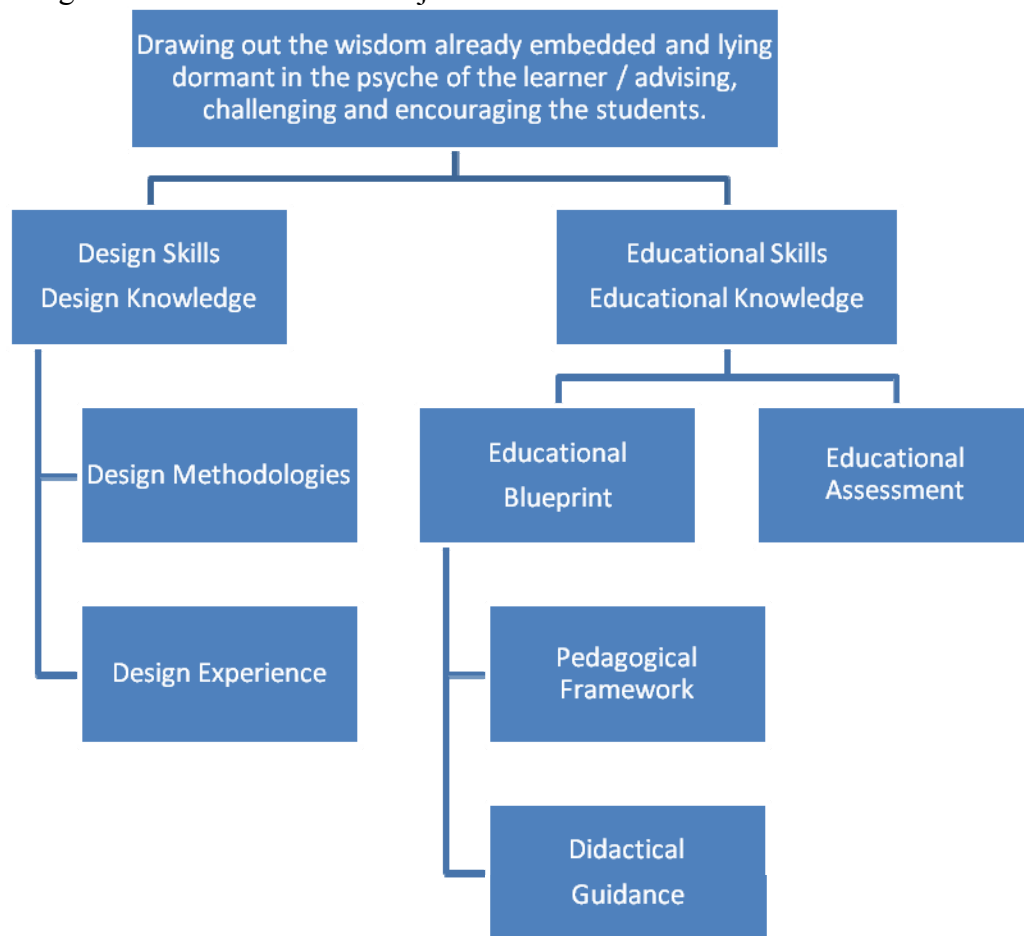


Figure A.3: Facilitator Functions.

As mentioned before, design is a complex activity, making design education even more challenging. Therefore, an educational blueprint (an instructive manual) detailing the steps of how to teach engineering design knowledge and how to develop engineering design skills is required.

A.1.2 EPIC's Requirement List

Government

The government is looking to capitalize on opportunities created by scientific discoveries. Intense emphasis has been directed to producing engineers who can invent new products and services, create new industries and jobs, and in turn generate new wealth to better today's economy. Therefore, it is required that student leave EPIC with an experience that would only contribute to their qualifications to enter today's competitive economy. The Challenge is offering this opportunity to students while maintaining government projects classified and under correct management.

Students

Students require an education that will give them a competitive advantage over students of other universities and countries. This implies an education that challenges them to think, motivates them to assist school, makes them feel free to explore and propose ideas, and surprises them with new knowledge and new methods of lecture and learning that keeps their interest awake. Also, having a facility that obtains sufficient tools and resources to carry out their projects would be ideal.

Faculty

They require an institution that supports them in their projects; assist them in the areas of knowledge where they are not the experts but need to implement in their endeavors. They would also require sufficient resources to be able to guide students in performing their projects. Professors would look for Technical and academic support (labs, knowledge) from different departments on each project (Multidisciplinary collaboration).

Industry

The industry requires professionals with technical and management skills that have project related experiences. Moreover, the industry needs professionals that can adapt easily to constant change and cyclic challenges with fresh minds that can think out of the box (creativity). Professionals able to adapt to multidisciplinary projects (student related). They require someone that will provide solutions.

Prospective

Prospective students require inspiration, a place to aim for, an ideal to follow and aspire to, where they can feel as a goal to reach and as a local proud.

Social

They require solutions to their daily problems, products and services that could improve their quality of life, with tangible results (project related).

COE:

"DIVERSITY DRIVES INNOVATION

Our nation's future depends on its ability to be a global leader in innovation, and diversity is a key to innovation. Diversity has already developed into an economic asset for corporations, universities, and other organizations that hire engineers and computer scientists. The innovation advantage created by a diverse workforce includes a diverse set of cognitive tools, and identity diversity (e.g., race and ethnicity) contributes significantly to this cognitive tool set. Moreover, the looming engineering workforce shortage crisis, caused by a combination of baby-boomer retirements and flat engineering enrollments, can be solved by tapping into segments of the population currently under-represented in engineering, including Hispanics.

COLLABORATION CREATES OPPORTUNITIES

The success of our College depends critically on our ability to create opportunities for our faculty, students, staff, and other stakeholders. These opportunities will present themselves through collaborations at the individual and organizational level. Collaborations that we will promote include those among individual faculty members within and external to the College, among departments within and external to the College, between the College and other colleges/units at UTEP, and between the College and external corporations, universities and other organizations."

Support the COE Vision of: "A national model for urban institutions in engineering education innovation and in the integration of education, research, and engineering practice and entrepreneurship as a potent economic stimulator for the institution's service region."

Support the COE Mission of: "Innovative educational programs that contribute to effective learning for our students, and that prepare graduates to be leaders and innovators in a variety of fields, Implementation and commercialization of knowledge and technologies to solve critical engineering and computing problems, and Active partnerships and collaborations with educational, government, non-profit, and commercial organizations, maintaining a commitment to diversity."

Support the COE goal of: "Develop a broader, more flexible undergraduate level curriculum that prepares students for practice-based professional post-baccalaureate study, and nurtures leadership, life-long learning, and the broad skill set - including communications, ethics, technology management, creativity, innovation, and design - needed for professional practice.

Infuse entrepreneurship skills as required learning outcomes at all levels of the curriculum (B.S. through Ph.D.), and enhance opportunities for technology transfer and commercialization of senior design projects and thesis and dissertation research."

Support the COE goal of: "We will help students, faculty, and staff reach their educational and professional goals through experiences beyond the classroom. We believe that a significant portion of educational opportunities afforded to students at UTEP can be found in experiences that occur beyond the four walls of a classroom that wise and empathetic advising is critical to student success and that interaction with a knowledgeable and experienced faculty and staff is necessary for both. Increase participation of faculty, staff, and graduate students in professional development activities to increase their research and entrepreneurship skills."

Support the COE goal of: "We will identify and build upon our competitive niches....we will focus our investments of financial and human capital in five fields of study essential to human progress

Infrastructure and Sustainability

Biomedical and Health Systems

Information and Security

Advanced Manufacturing and Materials

Engineering Education Innovation

A.1.3 EPIC's Design Specifications

Geometry:

Facilities must be able to support multidisciplinary engineering projects, including all phases of the Program (Concept, Detail, Prototyping and Validation). The following are facility logistics:

- Power sources.
- Working areas and tools (for design, prototyping and validation).
- Safety lab measurements.
- Lab Rules.

Energy:

Resources for the Studio come from funding -Players (Clients, Designers, Mentors, Managers and Facilitators)

Forces:

Primary and secondary interests include:

- Credits for Students
- Attract prospective students to UTEP
- Support interdisciplinary interaction between professors
- Must generate complementary courses that enhance the skills of the designer
- Collaborate with external courses to match the goals of the COE and EPIC
- Educative – Learning for Students to gain competitive advantage through motivate

methods

- Entrepreneurial – Development of Products
- -Social – Development of Projects

Material:

- Projects – Must be open-ended, multidisciplinary, engineering related.
- Much smaller modular projects may be implanted to attract high school students.

Signals:

*Design Program Management

Safety:

*Intellectual Property Management

Studio Management (Ergonomics):

*Design Program Management

Production:

-Must be universally accepted model that can be easily adapted to other universities and countries.

Quality control:

-Must be measured, regulated and controlled by a board of multidisciplinary members.

Assembly:

-Must integrate of all resources involved.

Operation:

*Design Studio Management

-Public domain projects must have their own push. Otherwise would be difficult to carry out project (manager ownership).

Efficiency:

"The College must invest it's time, effort, and resources in an appropriately balanced set of activities that will optimize outcomes by expanding the opportunities available to our faculty, staff, and students."

Maintenance:

*Design Studio Management

Recycling:

-Must be designed so reuse of resources is feasible.

Costs:

-Must be cost effective (currency is man/time)

A.1.4 EPIC's Detail Guidelines

Multidisciplinary Collaboration

- Defined as people-to-people collaboration.
- Requires physical space, hardware and software for videoconferencing, interaction, meetings, etc.
- Requires knowledge support from TA's to guide and mentor project teams in their project collaboration.

Multidisciplinary Integration

- Defined as hands-on work on a multidisciplinary product.
- Requires physical space, tools, hardware and software for product integration.
- Requires knowledge support from TA's to guide and mentor project teams in their project integration.

Learning

- Coordination with Multidisciplinary and Departmental Senior Design.
- Organize training sessions, seminars, workshops, and presentations.
- Promote academic and professional visits, sabbaticals, and clinical cooperation.

Resource Network

- Offer a directory of services, labs, and contacts to support project teams.
- Science, Engineering, Arts, Marketing, Entrepreneurship, Psychology, etc.

Management

- Management of EPIC resources, hardware, software, space, staff, budget, etc.
- Project procurement.

Outreach

- Support the COE outreach activities at local high school in El Paso.
- Collaborate with ACES, EXCITES, Ambassador activities, etc.
- Take EPIC to students: Mobile Multi Media booth, hands on experience.

Machine Shop

- Fully functioning Machine Shop.

Design Research

- RA's from the Design Research Lab will be embedded in EPIC providing design knowledge support while conducting graduate and undergraduate research.

A.1.5 EPIC's Detail Functions

External:

Educate Eng. Students through Project related experiences

Develop Multidisciplinary Eng. Projects from Design to Launch

Overcome Interdisciplinary barriers

Deliver Quality Products (ideas and objects)

Contribute to UTEP Intellectual Property portfolio

Facilitate design methodologies to the Team

Provide a Design Observatory to LEADER

Network Teams with appropriate Mentors

Contribute to the latest innovation trends (environmental, health, etc)

Assist Mentors on their endeavors outside their area of expertise

Associate with other Universities and Design Studios

Internal:

Manage Engineering Projects

Integrate Multidisciplinary Teams

Search for: Clients, Projects, Teams and Mentors

Provide facilities to all of the players.

Education

Educate Eng. Students through Project related experiences

Project/ Program Development

Develop Multidisciplinary Eng. Projects from Design to Launch

Deliver Quality Products (ideas and objects)

Support Engineer Designers

Contribute to UTEP Intellectual Property portfolio

Facilitate design methodologies to the Team

Network Teams with appropriate Mentors

Assist Mentors on their endeavors outside their area of expertise

Contribute to the latest innovation trends (environmental, health, etc)

Research Support

Provide a Design Observatory to LEADER

A.1.6 EPIC's Working Structure

The working structure of this design studio is composed by four elements: projects (engineering design products to be developed), knowledge (engineering and educational information needed to develop the projects), facilities (adequate tools to develop the projects) and management (of all the previous elements).



Figure A.4: EPIC's Working Structure

A.1.6.1EPIC's Management

As any other lab, EPIC will need a management layer for its operation. We want to keep this to a minimum. We refer to budgets, staff, etc. One of the important elements we've identified is the relationship between EPIC and each department.

A.1.6.2EPIC's Projects

A key element is the multidisciplinary projects. We believe that good projects can be either interdisciplinary or multidisciplinary, and each department is already doing a good job with the first one. We need to bring truly multidisciplinary projects with the right characteristics and we need help with this.

A.1.6.3EPIC's Knowledge

We have been learning about what means design for each department, and what EPIC will contribute. We are developing a strong educational model that relates the desired design engineering skills to specific design tasks for the students. This model makes use of various pedagogical and didactical theories. We believe that the best teaching and learning model is the use of trained facilitators to help students succeed.

A.1.6.4EPIC's Facilities

This should consider: physical plant, tools, hardware, software, furniture, etc. The team is trying to prepare for a wide range of projects that build upon existing college's labs and centers. Construction has started and is scheduled for completion some time during Fall 2010 semester.

Physical Layout

The functionality defines the physical layout. (See Figures A.5 and A.6).

Integration Space

- Flexible space to work on integration projects, space and tools can be rearranged depending on the type of project.
- This is an open space area with utilities grid running on the ceiling (electricity, pressurized air, exhaust, water, etc.)

Collaborative Space

- Flexible meeting space to encourage collaboration; space and equipment can be rearranged depending on each team needs.

Management Space

- This includes helpdesk, lounge, and resource and reading areas.

Storage Space

- For collaboration equipment (videoconferencing, tables, chairs, etc.) and integration (hand tools, measurement equipment, laptops, portable LCD screens, etc.) equipment control.

Machine Shop

- Space for machines, material, metrology, tool room, welding area, and management office.

Design Areas

☐ Concept Generation

An area for the generation and exploration of ideas, with lounge style facilities, collaborative meeting space, teleconferencing capabilities, and multimedia equipment. The layout can be flexible, using removable walls (screens) and furniture to adapt to dynamic needs. Laptops with creative software are on loan as well as multimedia boards.

☐ Prototype Creation

Hands-on work areas to create prototypes, with stations for welding, woodshop, metals, plastics, gluing, etc. Use of these tools requires training and supervision and materials and access must be controlled. Exhaust may be needed.

☐ Machining & Fabrication

This area includes basic machine shop tools (saw, drill, guillotine, grinders, hand tools, etc.), desktop tools (CNC mill/lathe, plastic injection, metal casting, punch press, etc.), and will complement a necessary full-size state of the art Machine Shop.

☐ Integration Areas

Space necessary for students to work individually or as teams on their projects. It provides workbenches and storage furniture for teams and organizations such as ASME and SAE design projects. Space is rented based on defined priorities.

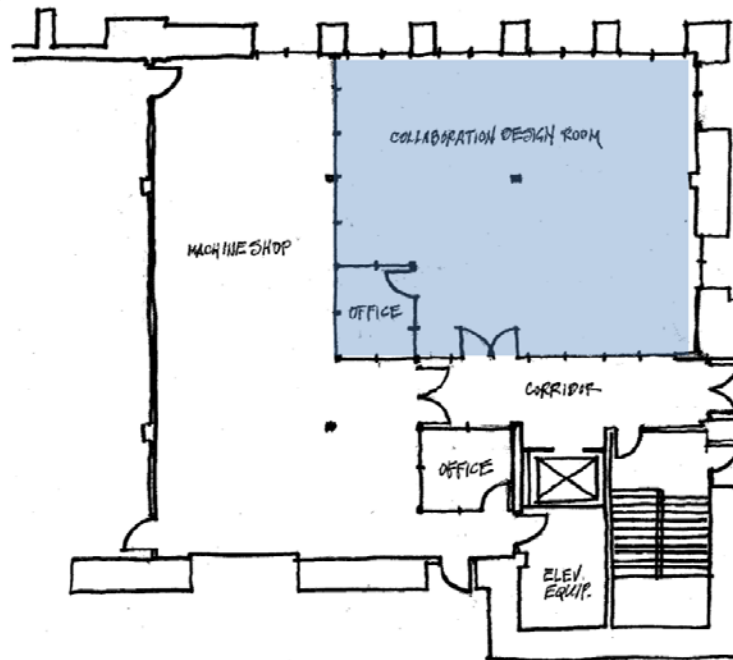


Figure A.5: EPIC's Physical Blueprint

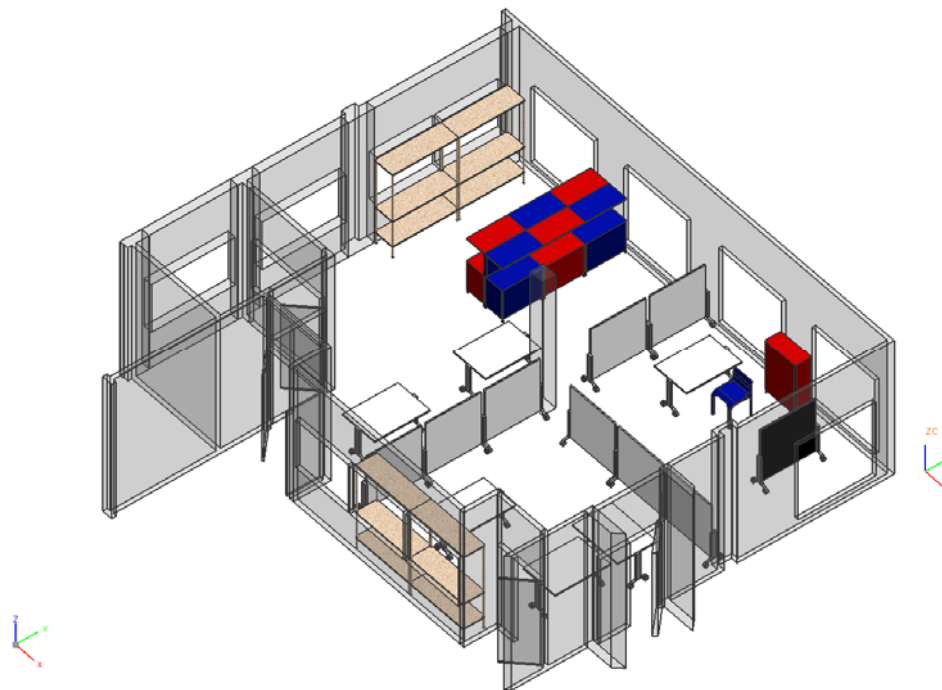


Figure A.6: EPIC's tridimensional model layout.

A.2.1 Engineering Design Companies

To exemplify the different types of companies that offer design services we selected some of the most recognized design companies and describe them very briefly by answering the next questions: What is their Design Process? What are their capabilities? What is their experience? Also it is specified the classification for each of the characteristics mentioned before. (See Figures A.7 to A.11).

CONCEPT DESIGNS <http://www.popconcepts.com/>

Dependency: Independent

Clients: Industry

Collaboration: Academy (Stanford)

Product Facet: TEB

Service: Independent PD and Producer

Concept Designs creates innovative point-of-purchase displays which enhance our clients' brand image and promote sales of their products.

ATLAS <http://www.atlassnowshoe.com/>

Dependency: Independent

Clients: Industry

Collaboration: Academy (Stanford)

Product Facet: TEB

Service: Independent PD and Producer

The Atlas story began in 1990 when founder Perry Klebahn, who was looking to snowshoeing to help recover from a motorcycle injury, became frustrated with the designs of the time. Klebahn soon developed his own ideas, and created a revolutionary new snowshoe as the thesis project for his graduate engineering degree from Stanford University's product design program.

FREEBOARD <http://www.freebord.com/main.html>

Dependency: Independent

Clients: Industry

Collaboration: Academy (Stanford)

Product Facet: TEB

Service: Independent PD and Producer

LIGHT AND MOTION

<http://www.lightandmotion.com/>

Academy (Stanford), TEB, Independent PD and Producer Dependency: Independent

Clients: Industry

Collaboration: Academy (Stanford)

Product Facet: TEB

Service: Independent PD and Producer

HID bike lights, underwater camera housings, underwater video camera housings and photographic equipment. Light & Motion was founded in 1989 by two Stanford students in a garage in Palo Alto, CA. It has since grown into a premier vertically-integrated manufacturer of outdoor recreation products.

XTRACYCLE

<http://www.xtracycle.com/>

Dependency: Independent

Clients: Industry

Collaboration: Academy (Stanford)

Product Facet: TEB

Service: Independent PD and Producer

Adapted bikes.

MIXER

<http://www.mixergroup.com/>

Dependency: Independent

Clients: Industry

Collaboration: Industry (DELL/HP)

Product Facet: TEB

Service: Consultant

IDEO <http://www.ideo.com/>

Dependency: Independent

Clients: Industry

Collaboration: Academy (Stanford)

Product Facet: TEB

Service: Consultant

They are a global design and innovation firm that works with clients to create positive outcomes for people and organizations.

Focus: Health, Education, Food, Environment, Entertainment, Transportation

Approach: (Stanford philosophy)

D2M <http://www.d2m-inc.com/>

Dependency: Independent

Clients: Industry

Collaboration: Academy (Stanford)

Product Facet: TEB

Service: Consultant

D2M is a full service engineering consultancy. Our international team of product development veterans specializes in concept generation, solution identification and engineering execution -- spanning concept generation through to manufacturing. Their services include: Product Development, Concept Development, User Interface Design, Sourcing & Business Development.

SLINGSHOT PRODUCT DEVELOPMENT GROUP

<http://www.slingshotpdg.com/>

Dependency: Independent

Clients: Industry

Collaboration: Academy (Stanford)

Product Facet: EB

Service: Consultant

Slingshot is a vertically integrated product development company that specializes in helping you with research, ideation, conceptual design, prototyping, engineering, design for manufacture, packaging, program management, and manufacturing coordination

IGNITION

<http://www.ignition.com/en/index.html>

Dependency: Independent

Clients: Industry

Collaboration: Industry

Product Facet: TE

Service: Independent PD

They are researchers, designers, engineers, and model makers. We push each other every day to create better ideas and turn them into products that connect with consumers. Simply put, we're here to help you be what's next.

TARLOW DESIGN

<http://www.tarlowdesign.com/>

Dependency: Independent

Clients: Industry

Collaboration: Academy (Stanford)

Product Facet: EB

Service: Consultant

They are a one stop shop for all your product development needs from initial product evaluation to final manufactured product in the box. We also help prepare patents and can work with you to plan a successful marketing or licensing campaign

CREATIVE ENGINEERING

<http://creativeengineering.com/>

Dependency: Independent

Clients: Industry

Collaboration: Industry

Product Facet: TE

Service: Consultant

They develop a product that will meet your requirements, function better, look nicer, and be less expensive to manufacture. We are engineers with a focus on function, but experience with products where aesthetics and human factors are critical. We excel at providing creative solutions to challenging problems, adding innovation to your products

GODDARD TECHNOLOGIES

http://www.goddardtech.com/Goddard_Process2.html

Dependency: Independent

Clients: Industry

Collaboration: Industry

Product Facet: TE

Service: Consultant

GTI is a full service Engineering and Industrial Design firm that supports clients with the design and development of their products

STRESS ENGINEERING SERVICES

<http://www.stress.com/consumer.php?iid=2&gclid=CJav0O6Es5kCFR0SagodOkJT7w>

Dependency: Independent

Clients: Industry

Collaboration: Industry

Product Facet: Technical

Service: Consultant

Stress Engineering Services is an industry leader in the predictive analysis of the performance of plastic components, simulation of manufacturing processes, and testing of materials. Our engineers use the latest design, analysis and experimental tools and methods to accurately model product and process performance, determine reliability, and to predict failures before they occur. At Stress Engineering Services we specialize in providing innovative design solutions for a variety of industries worldwide. From functionality and efficiency, to economics and safety, we have an in-depth understanding of the design challenges you face.

CREATIVITY ENGINEERING

<http://www.creativity-engineering.com/>

Dependency: Independent

Clients: Industry

Collaboration: Industry

Product Facet: Emotional

Service: Training

Training and team building seminars present a model in which your business, team, or organization will learn to leverage its inherent creative talents, increase levels of motivation and productivity.

CREATIVITY TRAINING INSTITUTE (CTI)

<http://www.creativitytraininginstitute.com/index.htm>

Dependency: Independent

Clients: Industry

Collaboration: Industry

Product Facet: Emotional

Service: Training

Idea generation, strategic re-alignment, creativity boot camp, etc.

TECHNICAL INNOVATION CENTER

<http://www.triz.org/>

Dependency: Independent

Clients: Industry

Collaboration: Industry

Product Facet: Technical

Service: Training

Technical Innovation Center, Inc. is one of the premier companies providing TRIZ training, consulting, and publishing services.

ICG T&C

<http://www.xtriz.com/>

Dependency: Independent

Clients: Industry

Collaboration: Industry

Product Facet: Technical, Business

Service: Training

Is a company operating within an international network united by the common goals and mission: to develop and bring to the market most advanced and practical methods, tools, and solutions which boost, leverage, and manage technology and business innovation.

NASA

http://www.nasa.gov/about/highlights/what_does_nasa_do.html

Dependency: Government

Clients: Government

Collaboration: Government

Product Facet: Technical

Service: Independent

NASA is mainly in to the technical part. It doesn't have an emotion side to it a company woks for us got according to the requirement. It has research in all field but the confidential one are not mentioned in the site. NASA has conducted or funded research that has led to numerous improvements to life here on Earth.

NASA conducts its work in four principle organizations, called: mission directorates, Aeronautics, Exploration Systems Science, and Space Operations.

NASA works on: Technical Excellence, Safety, Teamwork, and Integrity

NASA's Key management principle

- Lean Governance
- Responsibility and decision Making
- Sensible Competition
- Balance of power
- Checks and balances

SANDIA <http://www.sandia.gov/about/community/education/>

Dependency: Government

Clients: Government

Collaboration: Military

Product Facet: Technical

Service: Consultant

Sandia is a government-owned/contractor operated (GOCO) facility. Sandia Corporation, a Lockheed Martin company, manages Sandia for the U.S. Department of Energy's National Nuclear Security Administration. We seek collaborative partnerships on emerging technologies that support our mission.

Sandia National Laboratories, a government research and development (R&D) laboratory, values its interactions with private industry. Whether by purchasing goods and services, or transferring technology through Cooperative Research and Development Agreements (CRADAs) or licensing of technology, Sandia is committed to cultivating the highest quality relationships.

Sandia's mission is to meet national needs in four key areas:

Nuclear Weapons, Energy Resources and Nonproliferation, Defense Systems & Assessments, Homeland Security & Defense

Sandia works closely with industry, small business, universities and government agencies to bring technologies to the marketplace.

NAVY <http://www.nrl.navy.mil/content.php?P=AREA>

Dependency: Military

Clients: Military

Collaboration: Military

Product Facet: Technical

Service: Independent

Conducts exploratory and advanced technological development deriving from or appropriate to the scientific program areas. Within areas of technological expertise, develops prototype systems applicable to specific projects. Performs scientific research and development for other Navy activities and, where specifically qualified, for other agencies of the Department of Defense and, in defense-related efforts, for other Government agencies.

Specific leadership responsibilities are assigned in the following areas:

Primary in-house research in the physical, engineering, space, and environmental sciences.

Broadly based applied research and advanced technology development program in response to identified and anticipated Navy and Marine Corps needs.

NIST (Nation instate of standard and technology)

http://www.nist.gov/public_affairs/factsheet/strengthen_economy_safety.htm

Dependency: Military

Clients: Military

Collaboration: Military

Product Facet: Technical

Service: Independent

NIST manages some of the world's most specialized measurement facilities—including an unmatched and extraordinarily cost-effective NIST Center for Neutron Research user facility where cutting-edge research is done on new and improved materials, advanced fuel cells, and biotechnology.

That's increasingly important as new technologies become more complex and smaller—and more dependent on the most accurate possible measurements in order to move from theory, proof of concept, and prototypes into products. NIST's Center for Nanoscale Science and Technology (CNST) is a new effort, within the AML, that will bring together a multidisciplinary team from across NIST, industry, academia, and other government agencies to support all phases of nanotechnology development, from discovery

AFRL (Air Force research Lab) <http://www.wpafb.af.mil/AFRL/>

Dependency: Military

Clients: Military

Collaboration: Military

Product Facet: Technical

Service: Independent

It is a full-spectrum laboratory, responsible for planning and executing the Air Force' science and technology program. AFRL leads a worldwide government, industry and academia partnership in the discovery, development and delivery of a wide range of revolutionary technology.

A.2.2 Engineering Design Companies Classification Diagrams

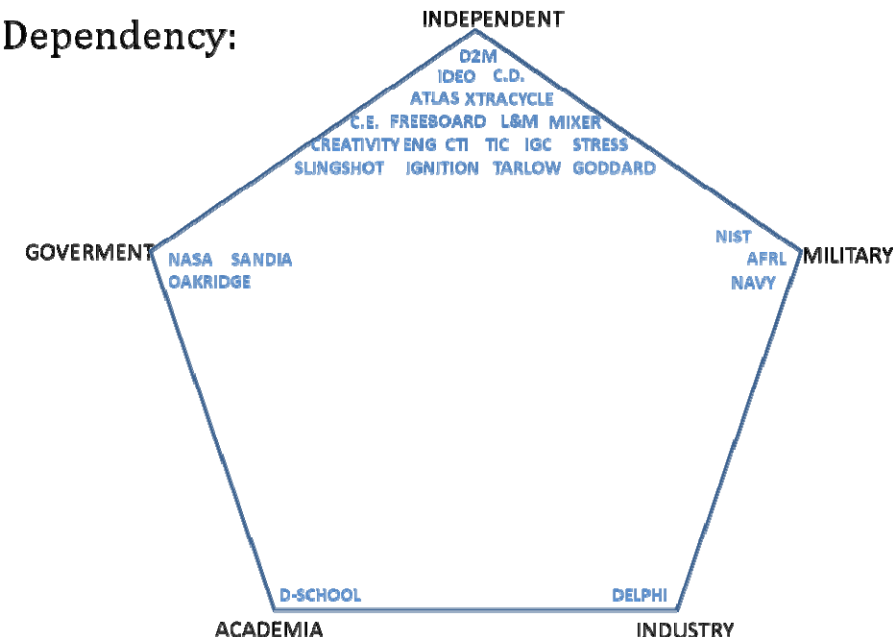


Figure A.7: Design Companies Dependency Diagram.

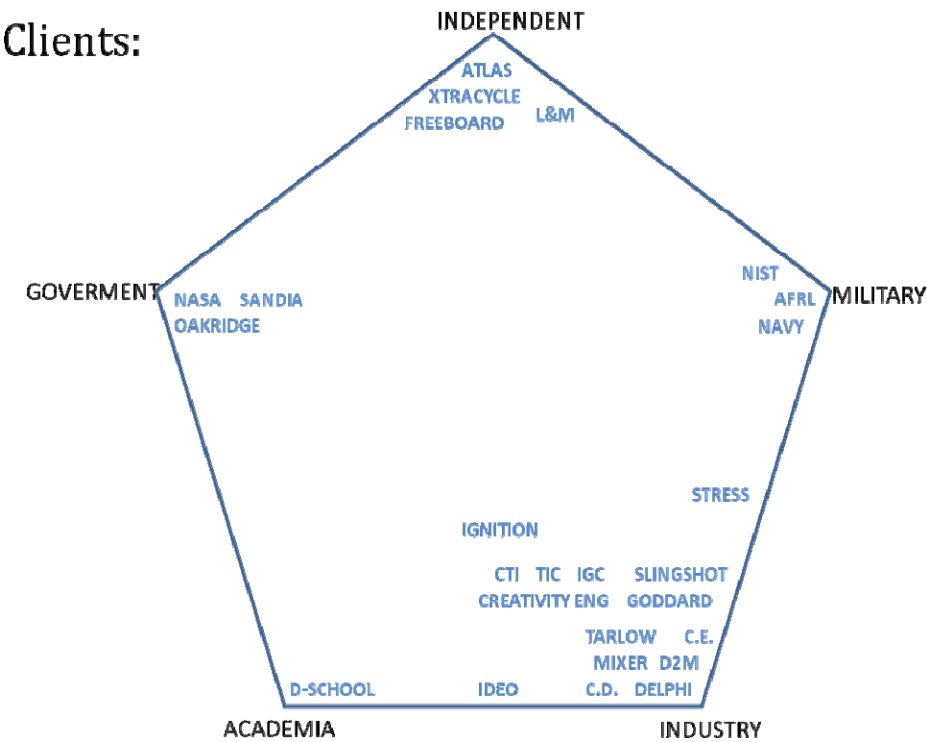


Figure A.8: Design Companies Clients Diagram.

Collaboration With:

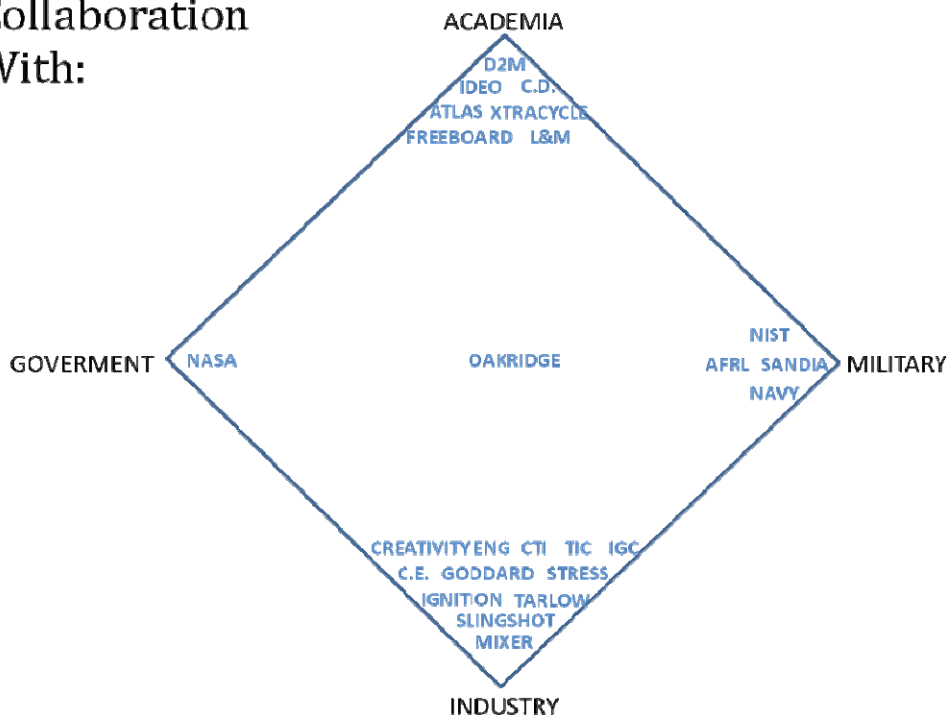


Figure A.9: Design Companies Collaboration Diagram.

Type of Service

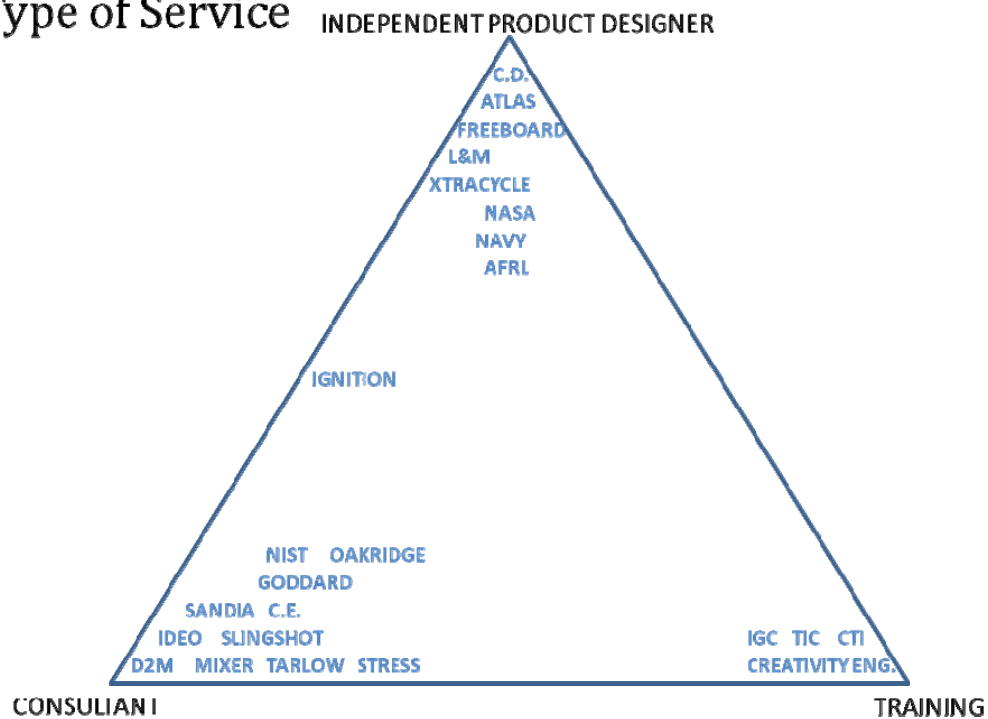


Figure A.10: Design Companies Type of Service Diagram.

Product Facet

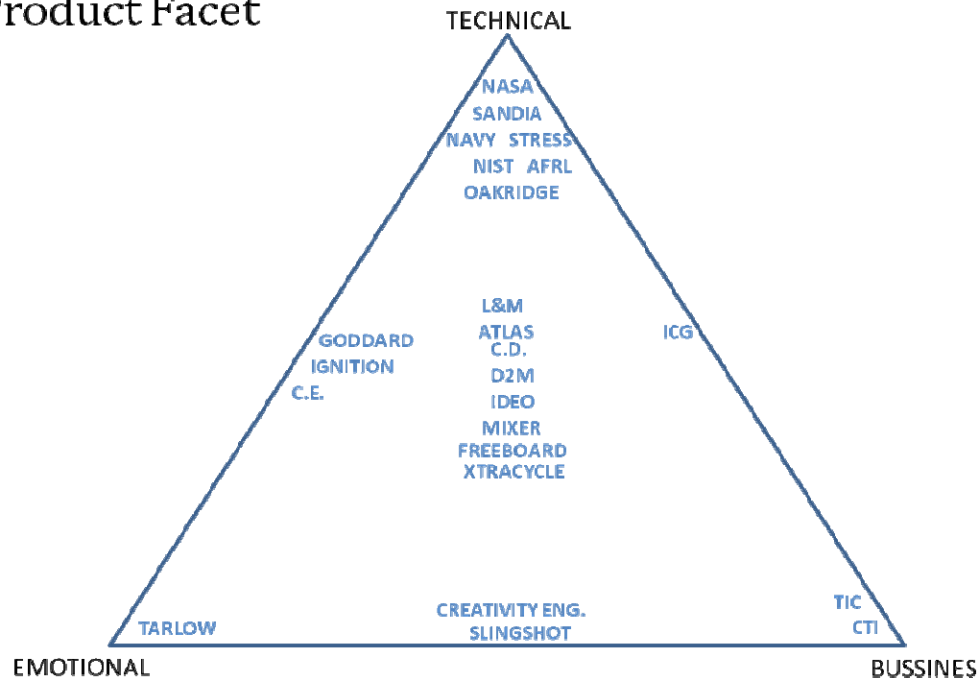


Figure A.11: Design Companies Product Facet Diagram.

A.2.3 Engineering Design Universities

UNIVERSITY OF ALABAMA

Not much information was found about research labs on creativity. There was one class “creativity in communication” by dr. Thomas B. Ward. This class examines the role of fundamental conceptual structures and processes in guiding creative or generative thought. It is mainly on the theory behind creativity. It was the only course like this found in Alabama and it is under the department of Psychology.

BATH UNIVERSITY

The Faculty of Engineering & Design comprises four academic departments covering the main branches of engineering:

- Architecture & Civil Engineering
- Chemical Engineering
- Electronic & Electrical Engineering
- Mechanical Engineering

The departments are united by a common interest in design, an area of strategic importance to all industrial sectors and one in which we have a high reputation in both teaching and research.

They have “The Innovative Design & Manufacturing Research Centre” which is unique in the UK in its emphasis on research in both design and manufacture, based on long-established research strengths in machine design and design information systems, and in manufacturing processes and systems. The Centre's work is widely supported by industry, especially from the aerospace and packaging sectors and with emerging strengths in shoe and electronics manufacture.

For Teaching they offer a PhD in “Information & Creativity” Design Information & Knowledge Research Theme (Doctoral Research).

BUFFALO STATE UNIVERSITY

They have the have the “International Center for Studies in Creativity” (ICSC) which utilizes diverse menus of programs for creative thinking, innovation and problem solving techniques.

For Teaching they offer BS and MS programs which are mainly educational offering 14 different courses in creativity such as “Principles in creative problem solving”, “creativity assessment methods and recourses” and designing and developing creativity education”. They have many resources such as a creative studies library and information center.

CAMBRIDGE

Philosophy: Cambridge Design capabilities and Research are centered in create knowledge, tools, understanding and methods meaning for the Industrial Application

Creativity Scope: Research on Innovation Management to generate products and services that exceed the expectations of all stakeholders. Identify the factors which influence creativity at an individual, project, process and organizational level.

They have the "Cambridge Engineering Design Centre" which undertakes research to create knowledge, understanding, methods and tools that will contribute to improving the design process. This will be achieved through:

- Innovative fundamental and applied research;
- Knowledge transfer via education, training, publications and industrial collaboration; and
- Promotion of the importance and benefits of engineering design in the UK.

CARNEGIE MELLON UNIVERSITY

This is a medium size university; they have a Mechanical Eng. program with several "clusters" of research and teaching one of them is "Design Innovation" which focuses on theories, methods and tools to advance efficiency and effectiveness in the product creation process.

Their research includes computational algorithms to generate and visualize new design concepts, cognitive research into human-based creativity, and formal models of decision making in the innovation process.

Their approach for either projects or research is by interdisciplinary collaborations and industry partnerships.

For teaching, they provide the basic design classes and laboratories.

They have the "Center for Production Strategy & Innovation" which seems to work as a consultant entity for marketing and product strategy.

Their Key Players are:

Dr. Jonathan Cagan who focuses on design theory and methods, product development and strategy, cognition in engineering design, and computational design tools, all for the early stages of product development. He has his own design company: "Integrated Design Innovation Group".

Dr. Kenji Shimada who focuses on computational methods and tools for two key tasks in innovative product development: idea generation and design optimization.

UNIVERSITY OF COLORADO AT COLORADO SPRINGS

This is a medium size university; they have a Mechanical Eng. program but there are no signs of design courses or labs at this program.

Even though they have a very unique program offered by the College of Engineering: “Bachelor of Innovation™” which is not a single degree but a family of related majors with a common core in innovation and entrepreneurship including a unique long-term, multi-disciplinary team experience..

The majors are:

- BI in Business Administration with emphasis areas in each major business sub-area,
- BI in Computer Science,
- BI in Computer Science Security,
- BI in Electrical Engineering,
- BI in Game Design and Development

Their approach is a multi-year multi-discipline team experience working on real problems with local companies, an understanding the innovation process of transforming ideas into sustainable societal impact, the basics of business, policy and intellectual property, and through their cross-discipline a deeper exploration globalization issues, creative communication, technology impact or business.

Their courses include classes like: “The Innovation Process” which reviews group exercises focused on improving team dynamics, brainstorming, conceptual-block busting and other creativity and problem solving activities. Other classes like: “Innovation Team, Reporting & Analysis” and “Innovation Team, Design & Research” have an evolutionary project base teaching method, which uses the philosophy of having several students of several semesters working for the same project in different levels of its development depending on their level of knowledge and skills.

Other classes are: “Intro to Engineering Design”, “Introduction to Engineering Innovation”. “Problem Solving through Game Creation” & “Improving Personal and Team Creativity”.

Their Key Players are:

Dr. Boulton, one of three El Pomar Professors at UCCS, is the visionary and champion behind the BI program. An innovator himself he has been involved in 3 successful startups, has 5 patents, 8 pending and over \$2M in research funding. His current company, <http://www.securics.com>, has 3 joint projects with UCCS employing 5 undergraduate students.

Dr. Ayen brings a wealth of business and management experience to the BI team, from being involved in startups to being Chancellor in universities.

Dr. Chamillard who leads the efforts of the BI in Game Design and Development (GDD). Dr. Chamillard's research is in CS education and in software engineering. He leads our Stegi@Work STTR effort a local company, a project that has employed 9 students, including multiple undergraduates.

DELFT UNIVERSITY

The Design Theory and Methodology group headed by Prof. dr. Petra Badke-Schaub carries out research and provides education on all aspects of the design process. The group is a fundamental part of the Industrial Design faculty providing structure for the studio-based design work of students and integrated in many other courses in the curriculum.

The Product Innovation Management department provides education and carries out research in the field of the business administration of product development. The most important subjects are marketing and consumer research, management and organization, and design methodology.

At Delft University of Technology we have a specific approach to organizational behavior that sets us apart from traditional OB programs at general business schools and fits better with the field of technology management

Organizational Behavior and Innovation:

1. Knowledge Processes
2. Organization Processes
3. Project Management

GEORGIA TECH

This is a large size university; they have a Mechanical Eng. program with no design branch defined.

Their courses include “Creative Decisions and Design”. Their goal is to teach fundamental techniques for creating, analyzing, synthesizing, and implementing design solutions to open ended problems with flexibility, adaptability, and creativity through team and individual efforts (looks very similar to our current DTM class at UTEP).

They have several design centers like “The Design & Intelligence Laboratory” which conducts research on design cognition and design AI. Also they have the “Robust Design of Complex Engineered System” which focuses on theories and methodologies of engineering design. Other design centers are: “Optimal Topologies and Reliability-based Systems Design”, “Simulation-Based Design Framework”, “Projects in Self Designing Systems” and “Interdisciplinary Design with Manufacture Integration”.

They look like having a very strong and organized research organization which uses design as a tool for solving many types of problems, but does not look like they have a “school” or “studio” where they could focus their resources to solve these problems.

Their Key Player is Dr Janet K. Allen whose research is in the area of mechanical engineering design and design education.

HARVEY MUDD COLLEGE

This is a small size college focused on sciences programs. Among them they have the Mechanical Eng. program that provides a broad-base “hands-on” experience based on several “clinics” which are courses that focus on the development of projects during several semesters.

They only do teaching for undergrad students; they don’t do any kind of research.

Their Key Player is Dr. Clive Dym how has many years of experience on design teaching.

JAPANS ADVANCES INSTITUTE OF SCIENCE AND TECHNOLOGY (JAIST)

JAIST is focused on knowledge creation education with its major goal to promote research and development of knowledge creation support systems and knowledge creating environments and apply them to real life problems. This is done by studying group decision making skills from the perspective of cognitive science. This university is mainly based on education, there have several projects based mainly on education and not industry.

MIT

Research in Creativity Scope:

Faculty is involved in a broad range of experimental, theoretical, and computational studies of creative and innovative processes. We are also developing new computer-based tools and systems as well as enhanced processes to support creative design activities. Simulations and experiments focus largely on design teams and the results are often interpreted using recent theories from cognitive science.

PENN STATE

Philosophy: The School of Engineering Design, Technology, and Professional Programs (SEDAPP) deliver effective engineering education through active, collaborative, project-based, and professionally oriented classroom experiences. SEDAPP offers a variety of programs that partner faculty, students, and industry in the study of real-life engineering problems.

Creativity Scope

The purpose of creativity is generating a large space of ideas and determines the best option that offers the better performance in a project-based.

STANFORD

This is a large size university; they have a Mechanical Eng. program with several branches and one of them is affiliated with the Design Group.

For Teaching they offer “The Stanford Program in Design” which is a program offered jointly with the Art Department that includes a BS and a MS degrees, concerned with conceiving and designing products for the benefit of society.

Their approach emphasis is placed on conceptual thinking, creativity, risk-taking, and aesthetics. They believe that this process requires resolution of constraints arising from technical, aesthetic, human and business concerns, there for their methodology is completely interdisciplinary.

They have the “The d.school” which is the Hasso Plattner Institute of Design at Stanford, is the place at responsible for creating their new culture of radical design collaboration (students and faculty in engineering, medicine, business, the humanities, and education).

Their courses include workshops and “bootcamps” in innovation and design including topics like: design processes, innovation methodologies, need finding, human factors, visualization, rapid prototyping, team dynamics, storytelling, and project leadership.

Their Key Players are:

Dr. David Kelley, a professor of mechanical engineering who has taught design at Stanford for over 25 years. As the founder of IDEO, one of the most renowned design firms in the world, David has prototyped, implemented and lived many of the d.school's guiding principles.

Dr. Larry Leifer, Director of the Center for Design Research which is a community of scholars focused on understanding and augmenting engineering design innovation and design education.

UNIVERSITY OF SYDNEY

The University's research spans three broad thematic areas; the humanities and social sciences that seeks to cultivate a civil society through visionary research and artistic creation; science and technology that offers insights into the natural and physical world and provides innovative solutions that will underpin Australia's future economic prosperity; and health and medical research that encompass research from agents of disease to increased patient care)The two year Master of Design Science Illumination Design and secondary stream) program allows for the combination of the Illumination Design stream and another Design Science stream for interdisciplinary study.

Their Key players by area:

Discovery Processes in Designing

Researchers: Dr Paul Murty

Design Styles and Design Behavior and Performance

Researchers: Ms Ellina Yukhina

Supervisors: Prof. John Gero

Dynamic Designs of Virtual Worlds Using Generative Design Agents

Researchers: Dr Ning Gu

Supervisors: Prof. Mary Lou Maher

Important topics discussed

Team, Concept, Creativity, Collaborative design, Research workstation

Vita

Gabriel Davila Rangel was born on April 16, 1978 in Mexico City, MEXICO. The eldest son of Jose Gabriel Davila Gallegos and Beatriz Rangel Carrillo, graduated in 2003 with a Bachelor degree in Mechanical Engineering from “Universidad Iberoamericana” in Mexico City and joined Delphi Automotive Systems in Ciudad Juarez, Chihuahua since 2004 to date, developing automotive products as full time Design and Computational Analysis Engineer. He joined The University of Texas at El Paso (UTEP) in 2007 as part time student to pursue a Master of Science in Mechanical Engineering. During this time he performed as Teaching Volunteer for CAD/CAM/FEA lessons of Unigraphics NX and as Research Assistant for LEADER Lab under Dr. Noe Vargas advising. His accomplishments include winning NSF-ASME Design Essay Competition with awarded travel grants to attend the ASME 2009 Design Engineering Technical conference in San Diego, 5 published papers on several conferences of Engineering Design Education (ASME, ASEE, Capstone Design, Frontiers in Education), 3 granted patents within Delphi Automotive Systems and 1 patent application within UTEP.

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This thesis was typed by Jose Gabriel Davila Rangel.