Improving Engineering Design Education: A Pedagogical Method-Objective Model

Noe Vargas Hernandez
Gabriel Davila Rangel
University of Texas at El Paso

The objective of this paper is to propose 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 can develop their design skills. From 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 important, to embrace such methodologies.

We present an approach to teach design engineering methods through three main steps: First, decompose the desired knowledge to be acquired by the student during the learning process in specific types of characteristics. Second, organize the characteristics of the methods by learning levels. Third, generate educational objectives for each of the characteristics of the engineering design method.

Noe Vargas Hernandez, nvargas@utep.edu

Introduction

Engineering design is defined as a complex cognitive activity in which the main objective is to change from a current to a desired status, thru a planed and organized process that involve: multiple disciplines, social collaboration, open-ended solutions, technical knowledge and advanced skills. Our mission as educators is to cultivate design skills and abilities in our students to achieve the highest competency, but design methodologies can be difficult to implement pedagogically, therefore the student struggles to learn, and develop design methods.

The objective of this paper is to propose a model to improve the engineering design education experience by building a prescriptive relation between a desired competency to develop in the student and a specific educational objective to be performed by the teacher.

We do this by analyzing the knowledge to be acquired by the student, understanding the theories behind education, searching for related art on this field and proposing a generic model. The paper is arranged in three parts, first a general background covering engineering design and education, followed by an analysis of the state of the art describing the problem, and third, our proposal to improve the educational method.

Background

Engineering Design Knowledge

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

Education: Pedagogy & Didactics

The main function of education is to improve the competency and capacity of the student thru the acquisition of knowledge and the development of skills within in a teaching-learning system. From a strategic point of view, education can be divided in to pedagogy and didactics. The first refers to the teaching/learning theory and strategy (what to teach?) and the second refers to teaching/learning tactics and methods (how to teach it?). 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).

Taxonomy of Educational Objectives

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"[1]. 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, with the purpose of providing a framework for educators to set learning objectives in their classroom. Since then, many improvements and criticisms have been made to this document; a recent evolution of it is Marzano's "New Taxonomy"[4] 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 previously proposed. Marzano's[4] taxonomy is a two-dimensional model. One of the axes consists of the hierarchy of "thinking systems" or levels of processing and on the other axis the "domains of knowledge".

The authors organize 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.

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

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.

State of the Art in Eng. Design Education

Most of the available literature on engineering design education relates to descriptive experiences from engineering professors in a capstone or senior design course[5]. Few papers present prescriptive proposals of how to implement educational theories in engineering design activities. In one example[3] the authors present (as pedagogy) a general model of curriculum for design engineering based on their needs of teaching design science, technical systems, modeling and disciplinary information. They also present (as didactics) a general model of 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. But they acknowledge that these proposals do not consider two key issues: How the students learn? and How to perform instructional methods for engineering design?

Another example of pedagogy[2] the author 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. The author 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 and learning practices.

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

Engineering Design Educational (Method-Objective) Model

Model Overview

Two main steps were defined for the overall model: engineering design method decomposition and engineering design method transformation in to educational objectives. The sequence of this model is a unique contribution of the authors and the transformation steps make use of well accepted educational theories (e.g. Bloom[1], Marzano[4]). Figure 1 presents the main steps of this educational model which will be reviewed in detail in the following subsections.

As explained earlier, there are various methods to perform engineering design, but there is no clear or unique taxonomy of such methods. Assuming that a method is selected, it is then decomposed following the proposed approach; obtaining with this a characterization of the method. It is suggested as future work that this characterization be used to develop a taxonomy of engineering design methods. The decomposed method is arranged according to Marzano's[4] levels of knowledge as a step to define educational objectives. These educational objectives then can be converted into educational tasks using Marzano's[4] guidelines.

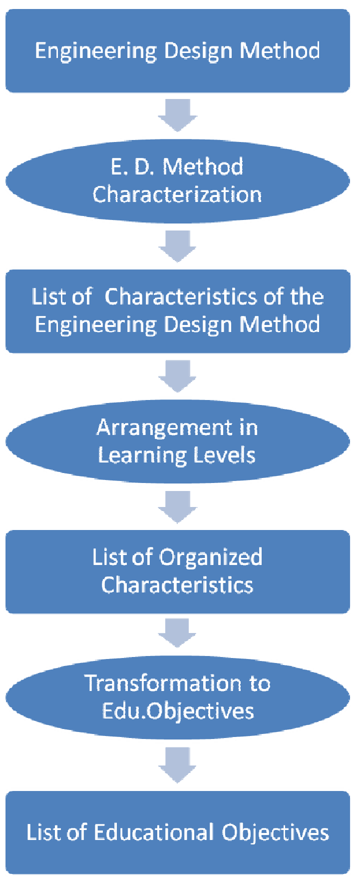

Figure 1:Educational Method-Objective Model Diagram

Engineering Design Method Decomposition

After selecting the design method the teacher must characterize it in detail in order to understand its purpose and the ways to accomplish it. This research proposes that any method 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 method, serving as a control system that will give feedback to the teacher on the acquisition of knowledge in the student. After characterizing in detail the method 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 method characteristic.

Method Characteristics Arrangement

Marzano's[4] 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. Therefore the design educator first needs to identify which operators of each thinking systems match with which each method characteristic. The function characteristic of the method will be mainly matched to the self-system operators that focus on the importance to learn such method. As shown in Figure 2, the effectiveness characteristics will be mainly matched to the metacognitive system operators which focus on the strategies of how to learn effectively the method. Finally the process characteristics will be mainly matched to the cognitive system operators that focus on the execution of learning. This arrangement of the method characteristics helps the teacher to set the optimal teaching sequence of each characteristic and then set goals (educational objectives) to accomplish for each operator.

Educational Objectives

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[4] as a template where the teacher only needs to "fill the blank" with the intended method to be acquired by the learner. The "knowledge sharing" method was chosen to exemplify the creation of such objectives using Marzano's "New Taxonomy of Educational Objectives"[4] as presented in Figure 2.

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 method 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.

METHOD DECOMPOSITION	MARZANO'S NEW TAXONOMY OF EDUCATIONAL OBJECTIVES[4]		
METHOD CHARACTERISTICS	**New Taxonomy Level**	**Operation**	**Educational Objectives for "Knowledge sharing" method**
METHOD FUNCTION	Level 6: Self-System Thinking	Examining Importance	The student will be able to identify how important the mental procedure of knowledge sharing 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 knowledge sharing and the reasons for this level of motivation.
METHOD EFFECTIVENESS	Level 5: Metacognition	Specifying Goals	The student will be able to establish a goal relative to the mental procedure of knowledge sharing 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 knowledge sharing.
METHOD PROCESS	Level 4: Knowledge Utilization	Decision Making	The student will be able to make decisions about the use of the mental procedure of knowledge sharing.
		Problem Solving	The student will be able to solve problems about the mental procedure of knowledge sharing.
	Level 3: Analysis	Classifying	The student will be able to identify superordinate and subordinate categories relative to the mental procedure of knowledge sharing.
		Specifying	The student will be able to identify logical consequences of the mental procedure of knowledge sharing.
	Level 2: Comprehension	Integrating	The student will be able to identify the basic structure of the mental procedure of knowledge sharing and the critical characteristics.
		Symbolizing	The student will be able to construct an accurate symbolic representation of the mental procedure of knowledge sharing 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 knowledge sharing, but not necessarily understand the structure of the knowledge.

Figure 2: Engineering Design Educational Objectives for “Knowledge Sharing” Design Method

Concluding Remarks

In this paper we 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. Our future work involves detailing and testing this model for three separated applications: problem solving method, multidisciplinary collaborative method and sustainability design methods, as starting points.

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