Chapter 1
Defining, Teaching, and Assessing Engineering Design Skills

Nikos J. Mourtos
San Jose State University, USA

ABSTRACT

The paper discusses a systematic approach for defining, teaching, and assessing engineering design skills. Although the examples presented in the paper are from the field of aerospace engineering, the principles apply to engineering design in general. What makes the teaching of engineering design particularly challenging is that the necessary skills and attributes are both technical and non-technical and come from the cognitive as well as the affective domains. Each set of skills requires a different approach to teach and assess. Implementing a variety of approaches for a number of years at SJSU has shown that it is just as necessary to teach affective skills, as it is to teach cognitive skills. As one might expect, each set of skills presents its own challenges.

INTRODUCTION

Design is the heart of engineering practice. In fact, many engineering experts consider design as being synonymous with engineering. Yet engineering schools have come under increasing criticism after World War II because they have overemphasized analytical approaches and engineering science at the expense of hands-on, design skills (Seely, 1999; Petrosky, 2000). As the editor of Machine Design put it, *schools are being charged with not responding to industry needs for hands-on design talent, but instead are grinding out legions of research scientists* (Curry, 1991).

In response to this criticism and to increase student retention, many engineering schools, including SJSU, introduce design at the freshman level to excite students about engineering. Freshman design also helps students put into perspective the entire curriculum, by viewing each subject as

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a necessary tool in the design process. Design is also globally dispersed in a variety of junior and senior level courses in the form of mini design projects and is finally experienced in a more realistic setting in a two-semester, senior design capstone experience.

The paper first attempts to provide a comprehensive definition of design skills. Subsequently, it presents a model for curriculum design that addresses these skills. Lastly, it presents ideas for assessing student competence in design. What makes teaching engineering design particularly challenging is that the necessary skills and attributes are technical as well as non-technical, and come from the cognitive as well as the affective domains. For example, the ability to define "real world" problems in practical (engineering) terms, to investigate and evaluate prior solutions, and to develop constraints and criteria for evaluation are technical skills, while the ability to communicate the results of a design, to work in teams, and decide on the best course of action when a decision has ethical implications are non-technical skills. Most technical skills are cognitive, however, there are several skills from the affective domain as well, such as the willingness to spend time reading, gathering information and defining the problem, and the willingness to risk and cope with ambiguity, to welcome change and manage stress. All these skills, technical and non-technical, cognitive and affective are essential for engineers, yet each requires a different approach to teach and assess.

DEFINING ENGINEERING DESIGN SKILLS

What is Engineering?

To define the skills necessary for design engineers we need to start with the definition of engineering itself. Nicolai (1988) defines engineering as *the design of a commodity for the benefit of mankind.* Obviously, the word *design* is key to the definition of engineering. Engineers design things in their attempt to solve everyday problems and improve the quality of our lives. As Theodore Von Karman put it: *A scientist discovers that which exists. An engineer creates that which never was*.

What is Design?

The next step in our search for design skills is to define design itself.

"Design is a process through which one creates and transforms ideas and concepts into a product that satisfies certain requirements and constraints."

Design requirements are usually technical and describe the performance expectations of the product, as specified by the customer or a perceived need. For example, a new passenger airplane may have mission requirements such as:

- A range of 3,000 km (i.e., the distance it will be able to fly without refueling).
- A payload of 100 passengers (i.e., the number of passengers along with their luggage it will be able to carry).
- A flight speed of 750 km/hr at a cruise altitude of 10 km.
- A takeoff field length of 1,500 m at standard sea level conditions.

The performance requirements specified by an airline (the customer), however, are not the only technical requirements that a passenger airplane must meet. To be certified, the plane must also satisfy additional airworthiness requirements. For example, FAR 25.121 part(b), refers to the ability of the plane to climb with one engine inoperative and requires that:

- In the takeoff configuration with the landing gear fully retracted but without ground effect the airplane must be able to maintain

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