Incorporating Realistic Constraints into the First-Year Design Experience

John K. Estell, Kenneth J. Reid
Ohio Northern University, j-estell@onu.edu
Virginia Tech, kenreid@vt.edu

***Abstract* - The purpose of this workshop is to present the Constraint-Source Model (CSM) framework to the first-year engineering community for review, discussion, and refinement. The CSM is conceptually based on four characteristics traditionally associated with the entrepreneurial engineering mindset: technical fundamentals, customer needs, business acumen, and societal values. Our hypotheses are that, by categorizing constraints such that the source of a constraint is also included, an engineering student can (1) examine each constraint from the point of view of a stakeholder from that source area, thereby allowing for a greater perspective on how such constraints can affect the design, and (2) gain an appreciation for the general education courses that provide that perspective. Resources developed to date in support of this framework will be provided. Attendees will have opportunities to apply the CSM towards different design scenarios, with facilitated discussion afterwards.**

Index Terms – First-year design, design process, criteria, constraints.

DESIGN PROJECTS IN THE FIRST YEAR

First-year engineering programs often include a design project within the curriculum. The introduction of the design project meets goals often mentioned in these programs: experiencing an engineering design process, incorporating some amount of hands-on experience (typically with a lower-fidelity proof of concept or prototype), and demonstrating that a design can meet the goals for some customer. These designs, like designs in the "real world," are constrained in many ways and must meet suitable criteria to prove their success to an acceptable level. However, the discussion of constraints and criteria is often limited in the first year curriculum; this can lead to a lack of appreciation for the consideration of realistic constraints and criteria within a design. Furthermore, criteria and constraints are usually covered near the beginning of the design process, and then no longer discussed. At best, students are asked to demonstrate that their design met the established criteria. The purpose of this workshop is to introduce a more robust and meaningful pedagogical approach towards realistic constraints, particularly in their introduction within the first year of engineering.

THE "ELITE EIGHT" ABET REALISTIC CONSTRAINTS

In the ABET Engineering Criteria (*Criteria*), Criterion 3 (Student Outcomes) states that engineering programs must have documented student outcomes, including:

(c) an ability to design a system, component, or process to meet desired needs within realistic constraints ***such as*** economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability (*emphasis added*). [1]

Although the phrase "such as" is present as a modifier indicating that the eight constraints that follow are to be treated as examples, many programs view this list – an "Elite Eight" of realistic constrains - to be exhaustive. By publishing this list in the *Criteria*, ABET has inadvertently created a two-tiered classification scheme that emphasizes the Elite Eight constraints to the exclusion of all other possible constraints. As a result, many instructors wind up "teaching to the test" by focusing only on the Elite Eight, and students (along with some faculty) mistakenly assume that these constraints are the only ones present in engineering design. Additionally, by not providing an appropriate context, ABET inadvertently discounts the very nature of constraints: that, instead of being holistic entities, constraints emanate from the various direct and indirect stakeholders associated with a product and its design.

Typical industrial designs involve far more constraints than just the Elite Eight presented in the *Criteria*, and the analysis is often more nuanced, such as making a distinction between the impact that the accuracy and the precision of a particular component can have on a design. Additionally, a constraint can take on multiple roles based on the point of view, or source, from which the constraint emanates: for example, the set of environmental constraints for an automobile includes not only how the design can affect the environment (such as the societal impact of carbon emissions), but how the environment can affect the design (such as the corrosive effects of road salt).

INTENT OF THE WORKSHOP

In a speech given in 1976, the industrial designer Dieter Rams expressed several of his core beliefs, including:

> *"You cannot understand design if you do not understand people; design is made for people."* [2]

Design is more than just the application of technology; design encompasses the human condition. Accordingly, to become good at design, one must become at least familiar with the various aspects of the human condition as experienced through the study of the humanities.

Products interact with people at several levels; therefore, designers also require at least an understanding of the pertinent concepts emanating from the social, behavioral, and biological sciences.

Products, once designed, need to be manufactured and marketed. Designers must understand the critical roles that both engineering and business play in getting a design out into the marketplace and accepted by consumers.

Accordingly, to become good designers, engineering students require a broad-based education, grounded not only in STEM (science, technology, engineering, and math) related topics, but also in the liberal arts and in business. This, therefore, is the underlying rationale for engineering majors to take general education courses.

The Constraint-Source Model (CSM) builds upon this educational framework by assuming that each constraint affecting a design can be modeled as an attribute derived from one of four possible source classification areas: business-driven, customer-driven, society-driven, and technically-driven. The CSM is also conceptually based on the four identified characteristics of the entrepreneurial engineer as identified in 2010 by the Kern Engineering Entrepreneurship Network (KEEN) [3]:

- An understanding of the **technical** fundamentals of engineering,
- An understanding of **customers**,
- An understanding of **business** to support the organizations in which they work, and
- An understanding of **societal** values.

Under the Constraint-Source Model a pedagogical framework is provided, primarily through sets of questions for consideration, to assist engineering students in their efforts to identify the constraints associated with a design by leading them in asking the right questions. The CSM will be explored in the workshop through planned activity sessions, with the application of appropriate sets of questions for sample projects either near the beginning or final stages in their design process. The activity sessions will be followed by facilitated discussion sessions. Workshop leaders include an ABET expert with both program evaluator and commissioner experience, and a director of multiple undergraduate programs with research experience in pedagogical development and studying student success.

BACKGROUND

For many years, students in the first-year introduction to engineering course sequence at Ohio Northern University have used poverty alleviation as a theme for their culminating design experience [4, 5]. In the spring of 2016, 30 project teams were assigned to design solutions providing either hydroelectric energy in Nigeria, solar water heating in China, solar air heating in Azerbaijan, or wind power in Peru. Toward the end of the design process, students were asked to reflect on an extended list of design attributes from which potential constraints commonly arise. Note that, prior to this exercise, the students were provided with only a minimal exposure to the concept of constraints. The list of technical-, business-, customer-, and society-driven design attributes from which the students were asked to consider whether a constraint existed in their resultant design is presented in Table I.

TABLE I
LIST OF DESIGN ATTRIBUTES USED IN PILOT STUDY

Design Attributes **Organized by Constraint-Source Area**	
Technical	**Customer**
Accuracy	Accessibility
Capacity	Aesthetics
Environmental	Efficiency
Manufacturability	Ergonomic
Mechanical	Health
Physical	Learnability
Precision	Maintainability
Reliability	Physical
Size	Risks
Thermal	Safety
Business	**Society**
Competition	Affordability
Ethical	Customs/Traditions
Internal Resources	Environmental
Labor	Health
Liability	Manufacturability
Manufacturability	Policy
Regulatory	Regulatory
Schedule	Safety
Supply Chain	Sustainability
Sustainability	

For each attribute, a question was posed; four quantitative responses (yes, no, unsure, and not applicable) and one qualitative response area for explaining the quantitative response was provided. For this pilot study, no further definition aside from the context of the question was provided regarding the provided designed attributes; however, students were encouraged to respond with attributes that they believed did constrain their design but were not present on this list.

Initial results showed a strong tendency for students to consider all technically-sourced attributes save for manufacturability as somehow constraining the design, which in many instances was more indicative of a lack of instruction (such as on the precision specified for the value of a component) than an actual constraint. The responses in the other three source areas were more distributed, but did exhibit interesting traits. As an example, the "Competition" and "Internal Resources" attributes sourced from a business-related stakeholder could arguably both fall under the Elite Eight's "Economic" constraint, but the two are sufficiently distinct that they each can be considered apart from the other. Accordingly, the students were asked to consider the following questions:

- [Competition] Has the product sufficiently differentiated itself from the competition in order to achieve an acceptable market share?
- [Internal Resources] Are there sufficient business resources (*e.g.*, budget, personnel) available for production?

The aggregate quantitative responses for these two questions are presented in Table II.

TABLE II
RESPONSE TO COMPETITION AND INTERNAL RESOURCES QUESTIONS

Attribute	Yes	Unsure	No	N/A
Competition	16	4	5	0
Internal Resources	14	8	3	0

These results, which were similar in distribution across the four design projects, shaded toward the presence of constraints that were successfully addressed, an observation reinforced by such qualitative responses as "Yes, the design is unique and cost effective which separate the product from the competition." However, it is worth noting that a reasonable portion of the cohort was uncertain about some aspects of the questions, which comments such as "We were never told about the resources available for production" being common. Additionally, given that the intent of the all four designs was based on alleviating the effects of poverty, comparison of the final designs to commercially-available designs may not be applicable. Overall, the responses raise interesting questions regarding how to best approach introducing first year engineering students to the various aspects of the engineering design process.

FUTURE WORK

Future research includes the study of (at least) two research questions evolving from the realistic coverage of constraints through the CSM:

- Does covering realistic constraints through a model that ties a design attribute to its stakeholder-oriented source lead to a better appreciation of General Education courses?

The authors hypothesize that, by presenting the CSM and related supplemental information in the first year, the coverage of realistic constraints will help students make a stronger connection to their general education courses as three of the four main areas of the CSM do not involve the technical requirements of the design – they focus on business, individuals, and society as a whole. Through a greater emphasis on the nature of realistic constraints, students are being given a reason grounded in reality to consider their general education courses as important to their future careers as engineers. The general education requirements for engineers play a critical role in design – no longer should engineering students (or faculty) view these courses as having "nothing to do with engineering."

- Does the early emphasis of constraints in a realistic framework lead to increased attention to such detail in engineering design projects in future years?

The authors hypothesize that the early introduction of these concepts will have a lasting affect throughout the remaining years of the student's engineering program.

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AUTHOR INFORMATION

John K. Estell, Professor, Computer Engineering and Computer Science, Ohio Northern University, j-estell@onu.edu

Kenneth J. Reid, Assistant Department Head and Associate Professor, Engineering Education, Virginia Polytechnic Institute and State University, kenreid@vt.edu