Making “Realistic Constraints” More Real

Kevin Nickels
Trinity University

The Engineering Science Department at Trinity University has made several changes to its capstone design course organization in order to increase student understanding and application of ABET’s Criterion 3. Criterion 3 states, in part, that a student should be able 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. The proposal process in Senior Design (ENGR-4381 and 4382) now evaluates the impact of these constraints on the project. Students are also led through several case studies addressing subsets of these constraints on example projects, discuss in class possible effects of these constraints on this year’s projects, and finally write a paper reflecting on the possible effects of a few of the most relevant of these constraints on their project. This paper reviews assessment data from before these changes, explains more fully the changes that have been implemented, and presents assessment data from students in the current course structure.

Corresponding Author: Kevin Nickels, knickels@trinity.edu

Trinity University is a small private liberal arts and sciences University in San Antonio Texas. The Engineering Science Department at Trinity University is an unusual one. We offer a broad-based curriculum with a grounding in the “fundamentals” of electrical, mechanical, and chemical engineering, along with some specialization through disciplinary electives. Students earn a B.S. in Engineering Science, and customize their program with help from their academic advisor. More detailed information on the program is given in a paper by Uddin[1].

Background and Course Structure

The Senior Design Course has been a mainstay of the engineering educational experience at Trinity for many years, and has been in its present form since approximately 1985. There is one course administrator, who coordinates the efforts of all the group advisors, sets course policy, gives guidance to the students on expectations, procedures, and policy, and provides any new course content either directly or via guests from the faculty and industry. Each faculty advisor works with a group of four to five students, providing technical advice, day-to-day project management, progress feedback, etc. The advisor has the majority of the grading responsibility for the course.

Assessment of Constraints

Criterion 3 (Student Outcomes) of the ABET Program Criteria[2] states that a graduating student will have, in part,

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.

The Engineering Science Department has identified three measureable criteria based on Educational Outcome C:

- C1: Determines design objectives and functional requirements based on a needs statement
- C2: Performs appropriate steps and methods for the design process
- C3: Identified and evaluates the potential impact of design solutions in terms of relevant issues and design constraints (i.e. economics, environmental, social, political, ethical, health and safety, manufacturability and sustainability)

Our process for assessing students’ performance on criterion C3 in particular showed a lack of depth of understanding of these concepts, and how these concepts would constrain a “real design”. For many years, the instructor asked students to write a paragraph or two on how each concept above affected the way that they approached their design and how it may have affected the outcome of the project. This assessment procedure has the advantage of being very little work for the students and faculty, and is not an uncommon indirect measure for this criterion (see, for example, Cornell’s Senior Design Website[3]).

In class, students were introduced to these concepts through a library research project where each group of students were assigned a concept to report on, conducted internet and library research, and presented the concept with background and examples to the class. The groups were distinct from the project groups, and the presentations included other concepts such as the design cycle, life-cycle analysis, robust design, etc. While the students seemed to absorb the importance and definitions of the concepts, advisors who reviewed these appendices felt that the students did not see the potential impact on <u>their</u> designs. In other words, they did not apply the concepts to their projects.

The appendix to their final reports, therefore, commonly consisted of a brief definition of the concept in question, followed by a statement to the effect of "This concept isn't applicable to our project" – repeated up to 23 times.

Goulding and DiTrolio[4], citing a similar assessment of their students, designed a project in a Software Engineering course to force teams to utilize relevant constraints. While the students appreciated the constraints and changed their approach to attempt to meet them, project efficacy with respect to the final design was mixed.

In 2007-2008, Trinity's appendix requirement was changed to remove some of the concepts not emphasized in the course, e.g. life-cycle analysis and robust design, and to focus on those constraints specifically called out in C3. Students were asked to choose, in consultation with their advisor, three or four of the most relevant of these constraints, and discuss how the constraint affected their decision-making and how it affected their project as a whole. The idea behind this change was to value quality over quantity, and to give the students time to reflect more deeply on the concepts most relevant to their project.

In 2008-2009, the report-based assessment was removed entirely, and replaced in 2009-2010 with a series of "reflection papers" as described below.

Changes to Project Development

At the same time, the development process for coming up with new projects was modified to specifically cite the constraints referenced in C3 as criteria in selecting a project for inclusion in the Senior Design course. In this interactive process, proposers (faculty, students, or industrial partners) move from a brief abstract to a 2-page proposal to an interactive presentation to the junior class and faculty, with feedback at each step from the current year's group of advisors and administrator. This process takes place throughout the spring semester of the Junior year. Through this feedback, one or two of the most applicable constraints are identified and the project statement and objectives are refined to highlight them.

This has the dual effect of emphasizing to the students proposing projects how important the constraints are and encouraging the selection of projects for which one or more of the concepts are organic.

Use of Case Studies

To reinforce the importance and applicability of the constraints, the library research project was replaced by a series of case studies. In each case, an advisor or guest speaker visits a regular classroom session and discusses two to three constraints. The concepts are defined and described, and the impact of the concept is discussed by the class in relation to a previous design project or project from the background of the speaker.

In 2007-2008, the topic structure was as follows:

- Power Plants – Discussion of Coal, Gas/Oil, and Nuclear Plants – addressing Social, Environmental, and Political Perspectives
- Production and Use of Personal Computer – addressing Sustainability, Environmental, Economic Constraints on design
- The IBM ProPrinter – addressing Manufacturability and Economic constraints in design

In 2008-2009, the first study changed to:

- Environmental, Social, Political, and Economic Impacts of Engineering Design – Ethanol Fuel and Engine Design

In 2009-2010, the topics included:

- Environmental Constraints – Automobile Manufacture and Use; Health and Safety Constratins – Power Plant Construction and Operation
- Mobile Phones – Are they safe? – addressing Ethical, Political, and Health & Safety issues with your design
- The IBM ProPrinter – addressing Manufacturability and Economic constraints in design

After the presentation, the class splits into small groups to discuss the possible impact of these new concepts on each of the current design projects. The outcomes from these discussions are typically bulleted lists of things for the design group to consider, such as these from 2009-10:

- Political: HIPPA Regulations (human testing) [Amputee Gait Analysis]
- Societal: taking patient's feelings into account in design Amputee Gait Analysis]
- Political: Regulations on how much CO_2 can be emitted [Absorber Column Remediation].

- Political: Follow alcohol sale laws for sale to minors and overconsumption [Festival Beer Vending Machine]
- Social: Aesthetics, Cost and Size Perceptions [Roof /Wall Joint Design for Prefab Houses],

where the bracketed phrase indicates the title of the relevant design project.

In the week following the discussion, each design group writes a one-page paper reflecting on the discussion and describing in more detail the possible impacts that the concepts could have on their design throughout the semester. For example, the Absorber Column Remediation group included a two paragraph analysis of the possible tradeoffs involving the exhaust stream based on regulations, as mentioned above, and on the health & safety of students in the lab where the column is housed.

> The exhaust steam of the column is another health & safety concern. High concentrations of noxious gases contained within the exhaust stream could create a hazardous environment for students. This problem could be addressed by simply venting the gases outside of the building, or into a working fume hood. The noxious gases could be vented into tanks and then disposed of later, or recycled back into the column. Also, an air filter could be placed onto the column, with the concentration of the noxious gas decreasing once the exhaust steam passes through the filter
>
> If the exhaust steam were ventilated into the atmosphere outside of the building, high concentrations of particular gases within the exhaust could be harmful to the environment. For instance, if CO_2, which is a greenhouse gas, is released into the environment in large quantities, it could contribute to global warming. The most obvious solution is to use a chemical that is not a greenhouse gas. However, other chemicals could be harmful to the environment without contributing to global warming. Therefore, a more logical solution would be to vent the exhaust stream somewhere other than outside of the building, such as into a fume hood.

The case study approach to design constraints is intended to give the students practice in applying the constraints to an applicable project or design. The hope is that this practice will lead students to understand the constraints more deeply and to apply them to their own projects.

Results

Design constraints, while being reviewed in Senior Design class and discussed therein, were often an afterthought, considered primarily when writing the final report. An excerpt from the "design concepts" section of the final report from a very good group in 2006 illustrates this:

> "Ethics – Social responsibility implies that the group ought to behave ethically and not attempt to sabotage others' projects or be involved with any similar deviant behaviors. The Internet provides the group with many useful programming and implementation examples that must be referenced if used. Additionally, the group needs to investigate copyright and intellectual property limitations on the use of these resources."

To be fair to the students, when a design concept was particularly relevant, the advisor and the students would often recognize this and would provide a more thoughtful analysis of the concept. But the application was very non-uniform.

In 2007-2008, the first formal assessment of criterion C3 as described above, advisors reviewed a section of the group's design reports, looking for their use of the design constraints. As mentioned above, groups were instructed to address "three or four of the most relevant issues" in this section. Of the five reports assessed, two groups were rated at the highest of four levels, with comments such as "Report addresses economic, environmental, manufacturability, and sustainability issues. Touches on social and political aspects…".

The remaining three reports were rated at the second highest level. Typical comments include "Some major constraints addressed well, a couple [relevant constraints] (political, ethical, manufacturability) not addressed. Overall, advisors and the administrator were pleased with the visibility of the constraints in comparison to past years, but felt that, in the words of one advisor, "a more rigorous analysis of all the [relevant] design constraints" was necessary.

The most recent results from 2009-2010 indicate similar results, with four of six groups being rated in the top category and two of six in the second for the fist case study, and four of five in the top category and one of five in the second for the second case study. Comments from advisors indicate that the major shortcoming is still the lack of depth of analysis of the effect that these concepts can have on projects. Table 1 summarizes these quantitative results.

Year	07-08	09-10
Meets Well	2	4
Meets Adequately	3	2
Partially Meets	0	0
Does not Meet	0	0

Table 1: Assessment of Criterion C3

More informal measures also indicate improvement in the visibility and application of these concepts. For example, a robot design group in Spring 2008 indicated that they reworked their design to include the smallest feasible variety of fasteners in their design after the discussion on the IBM Pro-Printer.

Spontaneous comments like this indicate that, for some students at least, the constraints are become somewhat more “realistic”.

Conclusions

By presenting “realistic constraints on design” within a case study framework, and by holding an in-class discussion followed by a reflection paper, the Engineering Science Department at Trinity University has been able to raise awareness and application of the concepts of economic, environmental, social, political, health and safety, manufacturability, and sustainability constraints on design.

Both informal and formal assessment indicate an increase in the understanding and use of these concepts, though of course more work is always needed in developing projects that organically require the concepts to be applied and in leading the students to leverage their understanding of the concepts to the design process.

Acknowledgements

Thanks go to Mahbub Uddin for the original structure of the “Case Study” approach.

References

1. M. Uddin, Multidisciplinary Engineering Science program at Trinity University. In *Proceedings American Society for Engineering Education Annual Conference*, 2004.
2. Criteria for Accrediting Engineering Programs Effective for Evaluations during the 2010-2011 Accreditation Cycle. ABET, Inc.
3. Mechanical and Aerospace Engineering: Senior Design Requirement. http://www.mae.cornell.edu/index.cfm/page/undergrad/apc/design.htm Accessed 12/21/2009.
4. T. Goulding and R. DiTrolio, Incorporating Realistic Constraints into a Student Team Software Project. In *Inroads – The SIGCSE Bulletin* Volume 37, Number 4, December 2005.