The Engineering Design Task Force Report

Questions concerning the content of this report should be directed to:

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The Engineering Design Task Force, initiated in winter 2018 after an initial consultation phase, is proposing the following two motions to be presented and voted on by the CEAB. Note that prior to calling the motions, we are requesting a consultation and comment period with the CEAB members, CEQB members, and various interested stakeholders as described within the document. We anticipate a consultation period of three months.

Motion 1: Adopt the following as a revision to the definition of engineering design

Proposed replacement of current text defining GA #4 (Design) and Criterion 3.4.4.3 on Engineering Design in the Accreditation Criteria and Procedures Document:

Engineering design definition

- for consistent use in assessment of Criteria 3.1 (and sub-criteria) and 3.4.4.3
- to replace wording in Definition of Graduate Attribute #4: Design
- to replace wording in Criterion 3.4.4.3

Criterion 3.4.4.3 *Engineering design is the process of making informed, thoughtful and creative decisions in devising a product, system, component, or process to meet specified needs. It is an open-ended and generative activity often iterative and multidisciplinary in which natural science, mathematics, and engineering science are incorporated into solutions that satisfy defined objectives within identified requirements and constraints. Typically, the constraints include economic, health and safety, environmental, societal, cultural, and regulatory aspects*.

Rationale

After consultation and discussion in a workshop in Quebec in September 2018 (including CEAB, EC, NCDEAS and HEIs) and a summit in Ottawa in February 2019 (including NSERC Design Chairs, HEI reps, and CEAB) and multiple teleconference meetings of the task force members, it was found that:

- There lacks a consistent definition within our criteria for both the inputs (AUs) and outcomes (GA) sides of our criteria.
- The current definitions do not capture the spirit of best practices in design engineering nor engineering design education.
- Industry and academia experts are generally proponents of the idea that design lies in the framing or context of the problem being faced.
- It is recognized that design experiences are typically handled and captured well in entry-level activities (i.e. first year) and capstone design projects. Senior capstone projects are usually given highest value in the design chain or sequence, while the entirety of the chain is equally important.

- Conversely, the middle-level (usually second and third years of program) design activities are commonly not dealt with in optimal or effective ways.
- These middle-level experiences generally involve development of skills in parallel with the design work. Appropriate handling of these two aspects is crucial to the development of high-quality design skills.
- Consistency and accuracy in the definition will aid HEIs, the AB, team chairs, and program visitors in effectively and reliably identifying engineering design within a program with greater repeatability across teams and institutions.
- It is important that the concepts, definitions, and interpretations discussed here be sent out for consultation and comment to our stakeholder groups, especially the NSERC Design Chair group and the CEQB. This should be done prior to acceptance and dissemination of these items as CEAB Policy.
- Past practice was a tendency to focus on and value capstone above all other activities. Spread of design activities throughout programs should be encouraged.

Motion 2: Adopt the following as an interpretive statement on engineering design

Proposed inclusion of the following text as an interpretive statement as an appendix to the Accreditation Criteria and Procedures document:

Interpretive statement on engineering design

It is recognized that the process, skills, and competencies associated with design are integral to the skills associated with engineering and that the activity of design is central to the practice of engineering. A key feature of good engineering-design education is the instilling of a mindset of creative exploration of a range of approaches to problems framed as open-ended, complex, and iterative decision-making exercises making use of well-founded skills and knowledge.

Design education relates to the development of students who approach the design process with goals related to exploring the range of possibilities to meet objectives as set out in problems they face. Design engineers will consider sets of constraints, engineering and scientific tools that can be brought to bear, and the requirements of the problem in arriving at solutions. These solutions are evaluated for their fit in meeting the objectives and also, but of no less importance, their societal, economic, ergonomic, and regulatory factors as appropriate.

What engineering design Is not

In order to aid HEIs and program visitors in consistently assessing the presence of engineering design, a statement of the limitations or what should be excluded from the activity of design can be useful. Engineering design is not being effectively accomplished if the following characteristics are present:

- immediate or clear solutions
- a single, correct answer
- solutions relating directly to component specification or sizing.

It is noted that the last point on component specification and sizing exemplifies a key feature that distinguishes design. If a student is faced with a problem of how to accomplish a task and needs to explore ways to achieve the goals within constraints, then the development and assessment of a solution can be considered as design. On the other hand, if the problem is framed more along the lines of choosing a size or specific component to accomplish a task, then the design aspect is significantly diminished. Problems that involve the specification and sizing based on standard tables and pre-engineered-type products may be considered more as analysis than design.

What engineering design includes

Conversely, effective engineering design brings together a variety of skills related to the design activity and may also involve skills specific to a technical discipline or multiple disciplines as needed. While practitioners bring varied approaches to design as applied to problems within their fields, some overarching characteristics of appropriate design include:

- development or fostering of creativity
- inclusion of open-ended problems
- development and use of modern design theory and methods
- needs or scope identification
- consideration to constraints such as
    - economic factors
    - health and safety
    - regulatory compliance
    - reliability
    - aesthetics
    - sustainability
    - environmental factors
    - ethics
    - societal impacts
- formulation of problem statements and specifications
- consideration of alternative solutions and decision making
- feasibility analysis
- production, manufacturing, or implementation processes
- detailed system description and documentation
- testing, prototyping, modelling, and validation

Engineering design should ideally be a culminating aspect of program integration and should demonstrate connections amongst the technical skills and knowledge presented in programs. As such, appropriate design education weaves through programs as a connecting thread. Design should occur in every academic year at a level commensurate with the abilities of the learner. Typically, opportunities for teamwork and the use of communication skills will be present as part of design activities. Successful achievement of the graduate attribute of design can be measured by the ability of a program to develop students who display the qualities associated with an effective design engineer. These qualities relate to competence in the aspects and skills described as being part of the overarching characteristics of design.

The key elements of the design process generally encompass:

- establishment of needs and description of scope
- definition of objectives and criteria, including goals, constraints, and available resources
- synthesis, including evaluation of alternatives and descriptions of tools and techniques
- analysis
- execution, including computation, prototyping, modelling, and/or construction
- validation and testing, including acceptance and implementation and evaluation
- reporting, including descriptions of the methods and processes applied to the design activity, recommendations, and statements on the limitations and constraints.

Design at all points in the curriculum of a program from introductory through intermediate to advanced levels should follow this defined process or some appropriate variation. As the competency of the designer increases, the complexity of the problem, efficacy of the solution, and sophistication of the tools brought to bear on the problem will increase. It is expected that students gain appreciation for the appropriateness of a design within context of the problem to be solved. This can be accomplished by consideration of technological and economic issues in addition to a demonstrated ability to understand the level of complexity suited for the situation of the problem. This type of sophistication in assessment of design by the student should itself advance as the program progresses from entry (first-year) to senior-level learning activities.

Descriptions of engineering design

In order to consistently identify engineering design within a program, the following descriptions are presented to delineate the types of activities and resulting outcomes that are appropriate for common design exercises. Engineering design can be considered as having four levels. Engineering design can exist at any of these levels; however, the final level is not common nor expected within engineering curricula. As a student progresses through their engineering programs, design experiences will expand to more complex and open-ended problems so that by the end of their education they are exposed to a range of design experiences and area able to employ increasingly sophisticated tools and resources to arrive at solutions. It is through this exposure that students come to appreciate the value of design at levels appropriate to their abilities, skillsets, and understanding. Students will then be able to make judgements about their own and presented designs for evaluation with respect to validity, feasibility, economics, and practicality.

1. Introductory, where design often follows an algorithmic approach. Set standards or rules are applied. While different techniques can be used, and alternative solutions can be found, usually these converge on essentially the same final result. At this level, students are developing skills in identifying design characteristics as they are learning to use these within the context and at a level appropriate to their knowledge and skillsets. The process of design should be clearly defined and understood.

2. A developmental level, where problems are clearly defined but differing solutions can be found, often by taking varying paths towards solving or dealing with the set of objectives. At this level, a small family of solutions with similar characteristics are typically found at the end of the design process exercise. Handling of the constraints and objectives is commonly approached using well-established methods and a clear process.

3. Complex, where a clear path to a solution is not generally apparent. Often this level involves bringing together differing methods for handling the conflicting objectives, decision making, and constraints to realize new and unforeseen solutions.

4. Original, where approaches to a level of significantly new paradigms in problems where engineers often need to go beyond established standards or codes, or work in areas where codes have not been prescribed. Such problems could involve radically innovative concepts that become developed through the steps for a final solution. Also, at this level, solutions may involve the combination of disparate objectives. Approaches to design at this level can deal with new areas where existing methods have not been developed. (As stated above, it is not normally expected that students will attain skills or understanding to work at this level within an undergraduate engineering program, unless the discipline deals with fields where codes and standards are not readily definable.)

It is recognized that design experiences are typically handled and captured well in entry level activities (i.e. first-year) and capstone design projects. However, senior capstone projects are usually given highest value in the design chain or sequence. Valuing the entirety of the chain equally is important for more imparting a more complete view of design to students. The middle-level (usually second and third years of program) design activities are commonly not dealt with in optimal or effective ways. These middle-level experiences generally involve development of skills in parallel with the design work. Appropriate handling of these two aspects is crucial to the development of high-quality design skills.

In assessing design, program visitors will consider the extent and quality to which students are presented with each of the levels of design. Further, program visitors will assess how this builds towards an overarching understanding of design in context of the discipline and the creation, development, and construction of devices, systems, processes, and methods both within the field and in interdisciplinary examples.

Illustrative example

To illustrate the concepts of engineering design and to provide a specific example, consider a problem of moving water up a hill and across a plain. The problem may be presented to the student as:

> *What size of pump is required to move the fluid at a prescribed rate?*

This would constitute a typical sizing or selection problem involving a single, or small set of possible answers. Alternatively, if the problem were framed as:

> *Our goal is to move the fluid from the starting point to its final destination. The quantity of fluid to be moved is given, as well as the desired time to accomplish the task. Factors to consider in finding a solution include piping, elevation, distance, flow velocity, and others. What potential solutions might be viable? What is the final selected solution and why?*

In this latter problem, the approach and specific techniques to be employed in finding solutions are not prescribed, and further, students are invited to explore options. This latter approach is more indicative of an engineering design experience. The application specific details will vary with level of the designer, from beginner (in lower years) to knowledgeable designer (near end of program) and the expectations in terms of sophistication should be commensurate. In the same way, the complexity of distinct objectives can be increased as the skill level of the designer rises. For example, the economic, environmental, and other factors can be brought to bear at appropriate levels.

Rationale

An interpretive statement will enhance consistency in assessment of the presence of engineering design in a program.

Further, the interpretive statement will provide guidance for HEIs to build, revise, improve, and modify their existing design content.