An Evaluation of Humanities and Social Science Requirements in an Undergraduate Engineering Curriculum

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Abstract

Engineering design is a structured, creative process, where engineers strive to develop solutions to perceived problems or needs by the application of theoretical and practical knowledge. The design process is a quest for technological objects, wherein the solution to the posed problem is intrinsic or inherent in the resultant object. However, the design solution [object] must exist in a real world context, which defines the extrinsic interactions or externalities of the object. These externalities include elements of aesthetics, economic factors, safety, risk, reliability, maintainability, sustainability; cultural, age, and gender appropriateness; environmental impact, energy efficiency, and end-of-life resource recovery, among others. It is within the realm of a design's externalities that engineers must apply knowledge and values that are derived from cultural resources normally outside of an engineer's training and experience. Because the externalities of a design are rising in importance, it is necessary to examine and evaluate the normal sources of such non-engineering experience, i.e. the humanities and social science components of an undergraduate engineering curriculum, to determine its adequacy. The humanities and social science components of an undergraduate engineering program are typically derived from the non-intentional "general distribution requirements" of the university and are not necessarily tailored to meet the needs of engineers. The humanities and social science components of Baylor's engineering programs are evaluated and compared to those of other major universities to identify negative trends and to evaluate the adequacy of these curricular components to inform and influence the extrinsic elements of engineering design. Several student design experiences from Baylor's engineering programs have been reviewed and evaluated to determine precisely how the humanities and social science curricular components support the engineering design experience.

Introduction

Design processes are at the heart of the engineering enterprise. Design is ultimately the task that engineering students must accomplish. The task of engineering educators is to prepare graduates who are designers. Quite often the academic role is seen as only imparting knowledge to the student, with carefully crafted curricula. Early courses impart foundational engineering sciences and mathematics knowledge followed by a succession of depth oriented engineering courses, culminating in a capstone design experience. These courses generally require students to have mastered the associated material from the prerequisite courses so that they can draw upon previous material at will as they learn design methodologies, techniques and strategies. In addition to the technical component, accreditation requirements delegate one quarter of the curriculum to communication skills and humanities and social science coursework. If humanities and social science curricular content can significantly influence the consideration of extrinsic elements or externalities of a design object, then the question of why these courses are not prerequisites for engineering design courses is worthy of consideration. In addition, the need for an intentional humanities and social science component as foundational, in the same manner as basic math and science requirements, is also worthy of deliberation.

Definitions

When reviewing the literature, there are many different definitions for design. Suh defines design as:

> "…the creation of synthesized solutions in the form of products, processes or systems that satisfy perceived needs through the mapping between FRs (functional requirements) in the functional domain and the DPs (design parameters) in the physical domain, through the proper selection of DPs that satisfy FRs." [1]

Dym and Little propose the following two definitions:

> "Engineering design is the systematic, intelligent generation and evaluation of specifications for artifacts whose form and function achieve stated objectives and satisfy specified constraints." [2]

After a lengthy attempt to clarify the definition, the authors state in more colloquial terms:

> "Engineering design is the organized thoughtful development and testing of characteristics of new objects that have a particular configuration or perform some desired function(s) that meets our aims without violating any specified limitations."

Eggert has the following definition:

> "Engineering design is the set of decision-making processes and activities used to determine the form of an object given the functions desired by the customer." [3]

These definitions evoke certain conclusions concerning design, which highlight how traditional design education is approached in the academic setting. The first is an emphasis on process, i.e. a process must be followed in order to accomplish a final design. The second conclusion is that design follows form and function. Form and function are two separate concepts but they are intertwined in ways that make it is hard to determine which, form or function, drives design. Function is often specified by the user or given in a statement of need with form generating how the design fulfils the required function. Surveys of several engineering design textbooks reinforce the notions of process and function driving form[1-7].

However, there is much more to a good design than just completing a process to achieve a given function in a particular form. The Accreditation Board of Engineering and Technology (ABET) hints at this with their definition of design:

> "the process of devising a system, component, or process to meet desired needs. It is a decision-making process (often iterative), in which the basic sciences and mathematics and engineering sciences are applied to convert resources optimally to meet a stated objective. … Further, it is essential to include a variety of realistic constraints such as economic factors, safety, reliability, aesthetics, ethics and social impact." [8]

Other Influences on Design

One concept being studied at Baylor University is how a designer's worldview influences the design process and design artifacts[9, 10]. They have found a definition of technology and design used by Monsma et al. to be very helpful in the understanding of design[11]. Technology is the product of the engineering design process. Monsma, et al. define *technology* as:

> "a distinct human cultural activity in which human beings exercise freedom and responsibility ... by forming and transforming the natural creation, with the aid of tools and procedures, for practical ends or purposes." [11]

These authors further assert that "doing technology [engineering] is not a [morally or ethically] neutral activity but one that involves valuing of a profound, fundamental nature."[11] The philosophical basis for asserting that valuing is inherent in the engineering design process [technology] is that "any set of standards for determining what does or does not constitute a solution to a problem must clearly lie outside the problem itself".[11] In other words, the evaluation of whether a particular design is a "good" or "bad" solution is not self-determined by a particular solution. Therefore, the presuppositions and pre-commitments of the designer [engineer] must play the central role in alternative design evaluation. In particular, one's worldview becomes an important factor in determining the final design solution.

Monsma, et al. also define *design* as a structured:

> "innovative activity whereby people [engineers] creatively use theoretical and practical knowledge and available energy and material in order to specify the size, shape, function, and material content of a technological object." [11]

Furthermore,

> "design results in a blueprint or set of detailed instructions for the physical characteristics of a technological object – either a product or a tool. Instructions for facilities and procedures needed to fabricate the object are included in these specifications."

This definition describes the design process as the quest for a solution to a problem that is intrinsic or inherent in the resultant object itself. However, the design solution [object] must exist in a real world context, which defines the extrinsic interactions or externalities of the object. These externalities include elements of aesthetics, economic factors, safety, risk, reliability, maintainability, sustainability; age, cultural and gender appropriateness; ergonomics, environmental impact, energy efficiency, and end-of-life resource recovery, among others. This is consistent with the ABET definition of design but goes much farther. It is within the realm of a design's externalities that cultural valuing is most intensely focused and therefore the area where an engineer's worldview may have the largest impact on the design process. Gojman reinforces this idea of valuing by defining three Axiological Dimensions, the systemic, the extrinsic and the intrinsic, as instruments to value, in a balanced manner, the goodness of a thing.[12] This valuing must be done in the three dimensions at the same time. According to Gojman, the systemic dimension refers to the technological aspect of a design or a set of properties that are finite and denumerable and associated with the domain specific knowledge (math and science) that is part of a typical engineering curriculum. Valuing in this dimension is not difficult. The intrinsic dimension concerns the functional properties and form of the design. Since these are inherent in the object itself, valuing in this dimension is not difficult. However, it is the extrinsic dimension, with virtually limitless inputs to consider that makes valuing difficult. It is this latter dimension of design, which is not or, possibly, cannot be addressed by the technical component of an engineering curriculum, for which the humanities and social sciences elements of the curriculum are manifestly essential.

Liberal Education

A recent report by Latzer entitled, "The Hollow Core: Failure of the General Education Curriculum," highlights many problems with liberal education component of undergraduate programs[13]. Latzer concludes that American colleges and universities are not meeting their responsibilities in providing the foundational subjects that ensure a solid general education. He states that our current college graduates often have only a thin and patchy education, with enormous gaps of knowledge in fields such as history, economics and literature. Some core courses are too narrow in their focus while others have questionable scholarly merit. Fifty major universities were surveyed for seven subjects that were considered essential to a contemporary liberal arts education. Of the fifty, only Baylor University achieved an "A" grade. Twelve of the fifty required no core or only one core course and received a grade of "F". Given this record, depending on the typical common core liberal education requirements to support the extrinsic dimension of the engineering design is foolhardy.

Curricular elements that support and develop a student understanding of extrinsic interactions or externalities is absolutely necessary. ABET, in its EC 2000 criterion[8], list seven program outcomes which can be directly affected by these externalities:

d. an ability to function on multi-disciplinary teams
e. an ability to identify, formulate, and solve engineering problems
f. an understanding of professional and ethical responsibility
g. an ability to communicate effectively
h. the broad education necessary to understand the impact of engineering solutions in a global and societal context
i. a recognition of the need for, and an ability to engage in life-long learning
j. a knowledge of contemporary issues

The liberal education component directly contributes to these outcomes but can be especially helpful in the areas of aesthetics, economic factors, safety, risk, reliability, maintainability, sustainability; cultural, age, and gender appropriateness; environmental impact, energy efficiency, and end-of-life resource recovery. While most programs have elements of liberal education, particularly in its humanities and social science courses, most programs do not understand or assess the impact of these courses on the student's design experiences.

Clive L. Dym of Harvey Mudd College states, that most engineering programs look far more alike than not.[14] He asserts that the curricula are highly constrained so significant change is hard to envision or implement. He observes four conclusions about curricula. First, long serial course sequences leave little flexibility and create disjointed or unconnected tracks in learning. Second, the first two years of many engineering curricula are taught by other departments (math, physics, chemistry, etc.) which emphasize a science model. Third, students believe that mathematics is the language of engineering. Fourth, engineering programs do a much better job of teaching analysis than design.

Steneck et al. have made recommendations concerning the liberal education component of engineering education[15]. They recommend that engineering programs integrate liberal education elements into engineering education instead of having them be extraneous requirement that students must meet. This integration should be comprehensive in respect to communication, professional responsibility, technology and culture, and intellectual and cultural perspectives.

Because most engineering curricula focus on the systemic and intrinsic elements of engineering design little space is left to address the foundational elements of extrinsic design. Therefore, it is necessary that the humanities and social science curricular component supply this foundation. Latzer's survey attempted to define a reasonable humanities and social science core as containing courses in writing or composition, literature, intermediate level foreign language, American government or American history, economic, mathematics and natural or physical sciences. Of this set, literature, foreign language and economic are the most pertinent to the foundational support of extrinsic design elements. However, the three relevant components in this list certainly lack imagination as well as breadth and possibly depth. They also lack any intentional support for the extrinsic elements of engineering design.

Blewett[16], from the University of Massachusetts at Lowell, recommends using clusters of specially designed liberal arts and humanities courses. These clusters target issues in technology, society and values; diversity and community; environmental issues and societal values; and global relations. While Blewett's approach is appealing, the large number of clusters available and the diversity of topics within each cluster make it difficult to guarantee even a small intersection of topics most applicable to the extrinsic design issue. However, the range of topics is well within the bounds needed to form a foundation for extrinsic design.

A search of the public website documents for a representative group of top-ranked public and private engineering programs demonstrated a wide diversity in these programs' liberal education components. Typical of most state university programs are core humanities and social science requirements that are not particularly supportive of extrinsic design. One such program requires six semester hours of American government, six hours of American history, and three hours each of fine arts or humanities and social science[17]. No recommendations are made concerning elective choices.

The highly ranked engineering program at Harvey Mudd College[18] has a very unique approach to humanities and liberal arts core. Beginning with a two-course sequence (seven semester hours) in "Introduction to the Humanities and Social Sciences", all students must complete thirty additional semester hours in "a coherent program planned with the approval of their humanities and social science advisor" and a three semester hour integrative experience "that explores the interaction between science, technology, and society."[18] The selection of approved humanities and social science course must meet both breadth and depth requirements. With adequate advisement a formable set of courses could be chosen to provide not only a foundation but also the walls and buttresses of a supportive structure to address extrinsic design issues.

Princeton University's engineering program[19] represents a middle ground between the typical state school and Harvey Mudd College. Princeton requires a twenty-one semester hour humanities and liberal art component with both breadth and depth requirements organized under six rubrics: epistemology and cognition; ethical thought and moral values; foreign language; historical analysis; literature and the arts; and social analysis. However, unlike Harvey Mudd College, there does not appear to be an intentionality requirement for a student's elective selection. The course categories however appear to provide a substantial foundation for the discussion of extrinsic design issues.

Rose-Hulman Institute of Technology[20] appears to have a similar approach to humanities and social science electives, with two course required in each of the categories of global studies; self and society; values and contemporary issues; and rhetoric and expression for a total of 32 quarter hours. If the elective selection in each of these categories were sufficiently comprehensive, it would appear that Rose's humanities and social sciences sequence provides significant material for addressing extrinsic design issues.

Eisenbarth and Van Treuren have undertaken an in-depth study of how Baylor University's engineering programs function within a liberal arts environment[21]. Baylor's curriculum represents a more restrictive approach to the humanities and social science component than most. The curriculum specifies two courses in great texts (ancient world, and medieval and Renaissance), two religion courses, an ethics course, intermediate foreign language, an economics course, and either a political science (constitutional government) or English literature course for a total of twenty-four semester hours. A student's elective choices are restricted to the selection of a foreign language and one of four possible ethics selections from business, medical, Christian, or engineering ethics. Missing from this list are courses in sociology, history, and the arts. Arguably, this restrictive set functions as a cluster in Blewett's schema but without the diversity that he champions.

There does appear to be a distinction evident in the public documents between public and private institutions in terms of the liberal education component. Engineering programs at most private institutions are typically embedded in a liberal arts culture that was well developed prior to these programs' advent. As a result, the liberal education components of these programs are stronger (greater depth), more diverse and more intentional. The programs at Harvey-Mudd College and Princeton University are examples. The public institutions founded primarily to support technical education appear to be much less committed to the principles of a liberal education component in their programs.

Design at Baylor

At Baylor University the first course which introduces students to the design process is EGR 1301, Introduction to Engineering. Here the students, in teams of four or five students, use a bridge design project to explore the design process. The students go through the steps of conceptual, preliminary and final design. The bridge is made of a prescribed amount of basswood and the students actually test a prototype and the final design to destruction on a tensile test machine. As part of the course, students also learn about economics and environmental impact of engineering in terms of sustainable and responsible design. Students are also taught about ethics, but, as is often true in design courses, these topics are additional topics and are not well integrated into the design experience itself.

The second exposure to design for Baylor students comes in the junior year in EGR 3380, Engineering Design I. The students are placed into four to five person interdisciplinary teams of electrical and mechanical engineers. The design project is typically a mechanical/electrical machine that does such tasks as sorting ping-pong balls or performing a robot challenge. This past semester saw a new emphasis, that of appropriate technology. Students were asked to develop an autonomous solar power source to pump water a prescribed distance and height. The application would be for use in a water system in a remote location as clean and abundant water is perceived as one of the world's major problems. While this new emphasis has tremendous potential, project results were rudimentary and incomplete. Observations of the final project presentations by the authors show that very few of the student teams considered extrinsic requirements. Most satisfied the functional requirements of the design, but did not satisfy the original design intent. This course also covers some elements of ethics and requires each student write an essay on a global issue, but these are again done at the conclusion of the course and little integration of extrinsic requirements during the design experience.

The capstone design course is EGR 4380, Engineering Design II. This course is taken in the last semester of the senior year. It is an interdisciplinary course with electrical and mechanical majors organized into team of typically 15-18 students. The project is usually generated from local industry requests. This past semester the project was to design a computer controlled exercise system. The project intentionally stepped outside the normal course boundary by including an artist on the design team. The artist was tasked with influencing the aesthetic appearance of the machine. The interaction between the students and the artist generated some psychological stress for both the students and faculty alike. Typically students are happy to accomplish a design in the semester course that looks nice (generally meaning painted and without rough edges) and works (meets functional requirements). Little thought is given to the extrinsic elements of the design. The original aesthetic constraint of this project was that the machines have a “high tech” look yet not intimidating, be unobtrusive, and easy to use. Cast aluminum was the method and material of choice. It was evident that students had not learned to be broadly creative or to be open to creative ideas outside their domain of expertise. Working with an artist added complexity to the project and required more time on the students' part to reconcile their rigid structural perspectives with the ascetic requirements of the design.

Exemplars

Healy at Santa Clara University champions integrating the extrinsic elements of design across the curriculum[22]. His faculty has developed an Engineering Handbook to show how extrinsic design factors relate to both the ABET requirements and the liberal education components of their curricula [23]. Their handbook consists of twelve chapters covering the topics of manufacturability, sustainability, usability, health and safety, environmental impact, ethical, social, political, economic, compassion, lifelong learning, and bringing it all together. This handbook is distributed to incoming freshmen and the faculty use aspects of it throughout the four-year curriculum. When the student reaches the senior year they have been exposed to extrinsic design concepts several times and they are included as a natural part of the design process.

Nair at Carnegie Mellon University studied decision making in the engineering classroom and concludes that in the "post conventional classroom" synthesis, evaluation, reflection and ethics needs to be part of every course [24]. While this may be very difficult to achieve in actuality, it could be accomplished in many engineering course through the integration of social and historical aspects of the technology under study, use of concepts maps to place the technology into social and historical context, the use one-page essays on related topics, searching for related news items and assigning decision making and ethics problems related to the technical domain.

Mikic and Grasso at Smith College have used design projects that challenges students to design toys that introduce children to the principles that underlie technology [25]. This design approach forces student to consider extrinsic design elements related to age and gender appropriateness.

Others have explored the use of art [26] and music [27] to stimulate diverse lines of thought about engineering design. Historical case studies in design are proposed by Gorman et al. [28]. They recognize that standardized curricula compartmentalize engineering and humanities and social sciences where real world engineering decisions do not. They discuss the importance of heuristics in design and invention as a sort of "rule of thumb" that engineers learn as short cuts to design solutions. Koen elaborates on the use of heuristics and integrates heuristics into the development of a worldview where all engineering is heuristic [29]. Ermer and VanderLeest study the difficulty of teaching ethics in design and propose the use of norms to evaluate designs for their ethical content. Evaluating ethics causes student to think in the broader context [30]. Still others are looking at culture and its influence on the design process [31].

Conclusions

Engineering design is a complex activity that involves some non-technical extrinsic elements which are not well supported by the technical (math and science) content of a typical engineering curriculum. All aspects of engineering design involve valuing, i.e. the consideration of trade-offs and alternatives, some elements of which are again not well supported by the technical content of a typical engineering program. Aside from the native cultural aspects of a student's personal life experiences, the educational resources for both value judgments and many extrinsic design elements are clearly located in the humanities and social science component of their degree programs. In the same manner in which mathematics and science courses are carefully chosen and specified to provide foundational elements for the technical content of an engineering program, the same intentionality and evaluation should be undertaken for the liberal education component of a student's undergraduate experience. Many good examples are readily available for evaluation and consideration, a few of which have been reviewed above.

Engineering faculty must also consider a more thorough integration of the liberal education elements into the engineering design experiences provided for students. Rather than selecting design projects that maximize the application and development of technical prowess and minimize the extrinsic design requirements, projects should be chosen which provide a more balanced approach to all possible aspects of a design. It has been demonstrated [24, 25] that this balance can be achieved through an intentional selection process. In addition, the valuing aspects of engineering design should be more thoroughly explored during the design process. Many decisions (tradeoff evaluations) are made without a clear understanding on the part of students as to how their particular life perspective (worldview) provides direct or indirect input into the decision process. Students are more likely to investigate these perspectives in the liberal education component of their curricula rather than the technical component and bring their insights into the design environment for integration if significant extrinsic design elements are present for them to engage.

Clearly, as the Baylor example indicates, engineering students can undervalue the liberal education component of their undergraduate program. Some of this may be transference from the attitudes and viewpoints of engineering faculty. Clearly, faculties tend to clone students in a manner which preserves their own engineering design experiences and viewpoints. To counter this tendency, the engineering faculty must generate opportunities to engage their liberal arts and social science colleagues in cross-cultural dialogs and, where possible, to involve them as instructional resources when teaching element of design.

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