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Defining Key Terms in New ABET Student Outcomes

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Abstract

In engineering design, it is necessary that proposed solutions to a problem fulfill not just technical requirements of the design problem, but also account for the real world context of the solutions. These broader contexts can be wide ranging and complex, simultaneously impacting the world in a variety of ways. When teaching an engineering capstone course, it is vital to provide students with the education necessary to address these issues. Indeed, the ABET Criteria for Accrediting Engineering Programs addresses this need in Criterion 2. Student Outcome 2 lists specific factors that students must consider when applying engineering design, including public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors. Furthermore, Student Outcome 4 addresses the ethical and professional responsibilities that students must consider in global, economic, environmental, and societal contexts. While these considerations collectively represent a wide range of potential real-world issues, differentiating between these categories can provide a difficult task, as many of these terms overlap in meaning. Student teams often struggle to understand the difference between each of these contexts and it can be difficult to assess whether each context has been fully considered. No specific guidance is provided, for example, when determining if a student has addressed cultural factors separately from social factors. The present paper seeks to more clearly define each of these terms in order to better assess student performance on the factors listed in this criterion. Examples of student work from a senior capstone course in mechanical engineering are presented, with student interpretation of each listed factor in the context of their own projects included.

Introduction

Engineering design is a process that inherently requires designers to consider a multitude of requirements and constraints and address the needs of numerous stakeholders. Traditionally, these requirements have been thought of from a purely technical standpoint, with engineering solutions designed to meet the needs of a specific customer. However, the solutions generated through the engineering design process have the ability to have a significant impact well beyond the intended use or scope of the design. Indeed, engineering solutions are woven into the fabric of everyday life and have wide ranging consequences to our society and our planet. These broader impacts require engineers to not only design for the wants and needs of a single customer, but to also incorporate the impact on all stakeholders.

In recent decades, engineers have had to transition from thinking about discrete problems and individual customer needs to reframing the design process as one that seeks to meet the needs of more diverse customers and demonstrates awareness of downstream effects [1]. Approaches such as sustainable design [2], human-centered design [3], value-sensitive design [4], and universal design [5] have gained popularity in pushing engineering design toward a more holistic thought process. These methodologies ask engineers to expand their design scope and consider the impact of their engineering solutions on a global scale, with new stakeholders from a wide range of backgrounds, countries, cultures, and experiences. Engineering designers must now constantly consider effects on the environment and natural resources, both for the sake of the present and for future generations. Engineers must design not just for individual wants and needs, but also for the public good.

These emerging issues have been noticed and adopted by many professional engineering organizations. A number of these groups have spearheaded initiatives to guide the future of engineering, resulting in downstream changes to teaching engineering design that include a focus on diverse stakeholders and concern for broader impacts. These organizations include the National Academy of Engineering Grand Challenges for Engineering, the United Nations Sustainable Development Goals, and ASME Vision 2030. The NAE highlights global ecological challenges like managing the nitrogen cycle and developing carbon sequestration methods, which have long-lasting environmental repercussions [6]. The UN emphasizes designing for the basic needs of all people across the globe, with goals such as no poverty, zero hunger, and clean water and sanitation [7]. ASME contends that "mechanical engineering practitioners will need to better understand the global marketplace in terms of economics, user needs, values and culture [8]." Each of these reports highlights the growing responsibility of engineers to consider global needs and impacts in the design process.

These broader implications of design solutions and changes to the responsibilities of engineers are reflected in changes made in 2019 to the ABET Criteria for Accrediting Engineering Programs, which describe the criteria that must be met by all accredited engineering programs and help to guide the direction of engineering education [9]. Specifically, the Student Outcomes listed under Criterion 3 were modified to include new language relating to these broader impacts. These Student Outcomes specify the necessary skills and abilities that an engineering program should foster in students to prepare them to enter the world of professional practice. ABET Student Outcomes 2 and 4 specifically inform design thinking with broader impacts. Student Outcome 2 lists, "an ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors." Student Outcome 4 lists, "an ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts." The various factors listed in Outcome 2 and the contexts listed in Outcome 4 directly reflect these new considerations of the impact of engineering solutions.

The inclusion of these broader contexts is a noble effort to emphasize the growing importance of these factors in the engineering profession, although these Student Outcomes are difficult to realistically implement in engineering curricula. It is unclear if these factors were selected by ABET intentionally to represent a complete set of factors in the design process or to merely communicate examples of broadening context for engineering design. Regardless of intent, ABET has produced guidance in regards to Student Outcome 2 that, "This does not mean that each of these elements must have a significant effect on the design — it just means that the program must show that students consider these elements as they engage in design [10]." Specifically, for Student Outcome 4, ABET recommends, "The emphasis for informed judgments is the ability of the student to consider impacts in all four contexts. When considering actual engineering situations, it is possible that only one or two impacts are major. Students must be able to consider all four, but it is acceptable to state that an impact is minor [10].” This guidance indicates that engineering programs must take the language literally and assess each of these listed factors individually rather than collectively, whereas students may consider these factors as aspirational for wide-reaching design implications.

The difficulty, therefore, comes in the mechanics of assessing terms that are sometimes vague and often semantically overlap with other terms. Some of the listed terms, such as “environmental” and “economic” are generally well-understood and can be fairly easily differentiated from the other design factors, but terms like “global,” “cultural,” and “social” overlap substantially and can be easily confused by students seeking to incorporate them into their design factors. ABET also fails to provide definitions or examples for these terms. Yet in asking for each specific factor to be considered by students and assessed by instructors, it is assumed that all parties are working from a common understanding of these terms.

In order to ensure that students are properly considering and addressing each of these criteria, it is important to develop a clear definition of each term. Ideally, these terms would be sufficiently independent so that it is clear when a student addressed one factor, but not another. In fact, many of these terms can be interpreted as having significant overlap in meaning and their differences are important, but nuanced. Given the difficulty in separating these categories for the purposes of assessment, the goal of this paper is to discuss how students interpret these terms with respect to the design process and to propose a set of working definitions so that students and assessors alike are working from the same understanding.

Student Examples

Examples of student work are presented below in order to show the types of design factors students consider to fall under each of the listed categories. The following work is from a Mechanical Engineering senior capstone course. In this senior capstone course, the course outcomes identically mirror the 7 ABET Student Outcomes discussed above. This ensures complete alignment between program objectives and those of the course, which is intended to be a two-semester culmination of the engineering curriculum. The examples below are taken from student submissions for a Project Concept assignment, which asked students to “Thoroughly research and describe factors that could affect your design in the following areas: 1. Health, Safety, and Welfare of the Public; 2. Global Factors; 3. Cultural Factors; 4. Social Factors; 5. Environmental Factors; 6. Economic Factors.” Responses below relate to the following projects: a jet boat nozzle designed to increase low-speed maneuverability (JET), an automatic pharmacy prescription retriever (SCRIP), a heavy-lift drone capable of carrying 30 pounds (DRONE), and a mechanical lifting mechanism for a drone that attaches to and lifts a payload (LIFT).

Area 1: Health, Safety, and Welfare of the Public

- JET: Reduce statistics on injuries caused by the current jet boat solutions and largest competitors.

- SCRIP: Increased prescription retrieval accuracy will reduce the amount of incorrectly filled prescriptions.
- DRONE: The drone could provide help in disaster relief efforts or deliver medication to disabled people.
- LIFT: A malfunction during flight could lead to a safety hazard.

Area 2: Global Factors

- JET: Source raw materials from countries with credible trade agreements and avoid countries with poor working conditions and labor laws.
- SCRIP: Reduced human contact will reduce spread of disease, such as COVID-19.
- DRONE: The drone has applications for the US Military. It could also be used to transport goods to geographically challenging locations, such as mountains or islands.
- LIFT: Many countries have unmanned drone regulations. The proposed solution lacks intercontinental range.

Area 3: Cultural Factors

- JET: Market towards cultures with access to bodies of water.
- SCRIP: This will save time, increase efficiency, and improve the wellbeing of customers.
- DRONE: Personal privacy needs to be taken into account. Cultural differences could impact human-drone interactions.
- LIFT: Countries with recent military conflict could lead to citizens being fearful of drones.

Area 4: Social Factors

- JET: Increased popularity of jet boats could lead to changes in the boating community. Licensing to a known manufacturer could increase product popularity.
- SCRIP: Automation will not replace human workers, but increase their efficiency and possibly create new jobs for maintenance.
- DRONE: This could lead to illegal surveillance or aid in delivering disaster relief.
- LIFT: The product will be marketed towards large corporations, so it should have a neutral design.

Area 5: Environmental Factors

- JET: The proposed solution could generate a larger wake, affect aquatic life, and increase noise pollution.
- SCRIP: Ensuring that the product uses a clean power source, utilizes recyclable materials, and there is a plan for the end of the product's lift will decrease environmental impact.
- DRONE: Using drones instead of cars and planes will reduce the carbon footprint of package delivery.
- LIFT: A drone for package delivery will decrease the reliance on fossil fuels, but could be a danger to wildlife.

Area 6: Economic Factors

- JET: The proposed solution could reduce maintenance costs, increase the life of the engine and be less fuel efficient.
- SCRIP: Fewer pharmacy technicians will be needed to work at the counter, which will help pharmacies save on cost. This could help reduce prescription prices and increase access to vital medications.
- DRONE: A drone for package delivery could increase profitability in the shipping industry, which could increase GDP.
- LIFT: Drones for package delivery could improve profit margins in the shipping industry.

Looking at these examples, the interpretations of each area vary widely from team to team. When asked to consider global factors, for example, these teams referenced trade agreements, disease transmission, military presence, geographic terrain, and local regulations. Similarly, multiple factors were considered by teams under different areas. For example, geographic terrain was discussed within the “Cultural” category by one team, but under the “Global” category by another. Discussion of disaster relief, military presence, privacy concerns, and worker efficiency also spanned multiple categories. It is clear that students have difficulty generating their own definitions of these issues in the context of their design projects and instructors have reported their own difficulty in determining whether or not students have adequately addressed the necessary factors. In order to solve these issues, working definitions are proposed in the following section.

Criteria Definitions

Due to the intersectional nature of these terms listed in the ABET Student Outcomes, it is desirable to generate a set of working definitions so that students and instructors can work from a common understanding of terms. The following section provides a set of working definitions of these listed design factors.

Student Outcome 2 - public health, safety, and welfare

The phrase “public health, safety, and welfare” is common among ethical codes of engineering societies, and it is included in some order in the AIAA, ALChE, ASCE, ASME, IEEE, and NSPE codes of ethics, among numerous others [11]. These three specific considerations are not new and these ethics codes trace back to at least 1912, but this particular phrasing was not previously included in the ABET Student Outcomes prior to the change in 2019 and care should be taken to define and address each term.

The first consideration is whether the adjective “public” can be distributed to mean “public health,” “public safety,” and “public welfare.” Given that these three terms are used in different orders in the various ethical codes mentioned above, it is reasonable to assume that all three phrases refer to the public. This is important in establishing that each consideration applies to the general public, implying that the health, safety, and welfare of all individuals should be considered, not just customers and end-users of the engineering solution.

To further separate these terms, the phrase “health” can be defined as the condition of being free from physical or mental illness or pain, whereas “safety” is the condition of being free from physical or mental injury or harm. The phrase “welfare” is tougher to define, but can be considered as the other basic necessary provisions to survive and be well, such as access to food, water, and shelter.

Student Outcome 2 - global, cultural, social, environmental, and economic factors

Here, the terms become difficult to differentiate, as many of them overlap in meaning. The consideration of “global” factors can be interpreted to point to design factors which vary across the world, considering differences in geography, available resources, and ecological conditions. While individually, each of these examples could likely be subsumed under another of the categories described below, global factors account for how each of these is different in different parts of the world. Similarly, we can also use the term “global” to refer to interactions between different groups of people, companies, and countries across the world and transportation around the globe.

The term “cultural” refers to the way that individuals from within a group of people live their lives, shown through their behaviors, customs, beliefs, norms, traditions, and even language use [12]. These cultural lenses impact how people view the world, make decisions, and help determine what is deemed acceptable or offensive.

The term “social” refers to the way that humans interact and relate to each other. This can incorporate the means of communication, but also considers that categories like race, gender, ethnicity, and class are constructs of society and inform how those individuals communicate. The term “social” also carries with it the different ways that humans organize together to form groups, such as marriages, families, and governments.

The term “environmental” refers to factors relating to the natural world. This includes both living organisms and their external surroundings that influence their survival and development. For the purposes of this definition, humans can be excluded from the living organisms included in “environmental” because they are already included in the “health, safety, and welfare” categories above.

The term “economic” refers to the production, distribution, and consumption of goods and services. On a small scale, this can include individual monetary transactions and the factors that affect supply, demand, and pricing. On a large scale, this can include the ways that these smaller markets interact to form local, regional, or national economies, which relate to things like income, wages, unemployment, productivity, and inflation.

While the above working definitions can form a basis from which to operate for students and assessors alike, there are many examples of factors that do not fit neatly into one category or another. Language, for example, informs multiple of the above categories. Language varies across the globe and has been created and changed throughout history because of the ways that humans and societies from around the world interact with each other, directly tying it to the “global” category. Language also relates heavily to “culture” in that it develops over time within groups of people and is tied inherently to so many of the behaviors and customs of a culture. Still, language is inherent to social interactions, and is heavily tied to social constructs through titles and honorifics, linking language with the “social” category as well. Another issue is the way that these categories interact. Religion, for example, can in some contexts be strongly tied to culture, where an individual’s religious beliefs inform their way of living and view of the world. In other contexts, religion is more of a social category, as human interaction is the primary reason that some individuals experience their religion. Due to these complex interactions, it could be argued that global factors moderate whether religion should best be considered within a cultural or social context.

Student Outcome 4 - global, economic, environmental, and societal contexts

The terms contained in this Student Outcome largely overlap with those from Student Outcome 2, described above. The terms “global,” “economic,” and “environmental” can retain the same definitions in the context of this Student Outcome. The different term in this Outcome, “societal,” is most easily defined as a combination of “cultural” and “social” from above. This can include both the norms and customs of a group of people, but also the ways that they interact with each other and the socially constructed institutions that inform those interactions.

Future Work

In future work, student-generated definitions will be solicited and analyzed to determine common misconceptions, inaccuracies, and sources of confusion. Students will also be provided with the definitions proposed herein in order to refine their project-specific design considerations. The hope is to determine whether students can appropriately apply these definitions to their unique projects.

Conclusions

Changes to the focus of engineering design in recent decades have led to a broadening of the scope of factors and potential stakeholders that must be considered throughout the design process. These changes are reflected in the new ABET Student Outcomes, although the criteria listed are difficult to interpret and are often intersectional or interdependent. Examples of student interpretations of these design factors were included, along with proposed working definitions for each of these terms. It is the hope of the authors that these definitions will help to improve both the work of students as well as aid in assessment.

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