Designing for Success: Developing Engineers Who Consider Universal Design Principles

Kimberly Edginton Bigelow
University of Dayton

Abstract

Engineers must design for a diverse group of potential users of their products; however, engineering curricula rarely include an emphasis on universal design principles. This research article details the effectiveness of a design project implemented in a first-year engineering course in an effort to raise awareness of the need for engineers to be more inclusive when designing. Students were asked to apply universal design principles to redesign an engineering laboratory to make it more usable to all, including individuals with disabilities who use the room. A representative from the university's disability services staff, as well as individuals with first-hand experience of disability, provided guidance to the class by serving as project mentors.

Design decision analyses were reviewed to determine the specific criteria student teams believed were most important in identifying specific design ideas to pursue. These analyses were used to evaluate the success of this project in helping students be more cognizant of the need for designs to be flexible, versatile, and universally designed. These criteria were compared to projects from previous classes in which universal design had not been explicitly addressed. Results indicated that students who participated in the universal design project were much more likely to consider criteria related to universal design principles, though they identified accessibility as more important than the more overarching goals of achieving a universally usable design. Results suggest that such a universal design project is one possible model to better prepare engineering students and that the model can be strengthened through involvement of disability services professionals.

Keywords: Universal design, engineering education, project-based learning, design decision analysis

From tennis shoes to automobiles, engineering design is an integral part of everyday life. Even products as simplistic as paperclips and drinking cups have been highlighted as examples of products with a deep and rich history of engineering design and product evolution (Petroski, 1994, 2004). More sophisticated designs such as medical devices, wind turbines, and robots impact the global community in even more significant ways – improving quality of life, preserving natural resources, and enabling safer ways of doing dangerous tasks. A common thread of all types of engineered products, whether a kitchen can opener or a motorized wheelchair, is that each is used and maintained by a diverse group of individuals. As such, universal design considerations have an important place in engineering design.

Engineering Design Process

To fully understand the role these considerations can play, it is important to first understand the engineering design process and how it is taught in the engineering curriculum. Knowing this allows a better understanding of the challenges and opportunities for making engineering design – and designed products – more inclusive to all.

The term *engineering design* refers to the end product that is created and produced, but even more so to the systematic, and iterative, process that engineers go through to reach the end deliverable (Dym & Little, 2009). In the engineering curriculum, this process is often taught through a senior capstone design course, in which students form design teams to work on real-world industry-sponsored projects (Dutson, Todd, Magelby, & Sorenson, 1997). More recently, programs have initiated first-year “cornerstone” classes that mimic this experience but introduce students to the process during their freshman year (Dym, Agogino, Eris, Frey, & Leifer, 2005).

The engineering process is very much driven by people – from the client who has a problem that needs to be solved, to the design team that works to solve it, to the potential users who will interface with the solution. Throughout the engineering design process the interactions between these three entities are integral to the process’s success.

This becomes most clear during the Problem Definition phase of the process, in which the design team must question the client and potential users to better understand the problem they have just been presented (Dym & Little, 2009; Pahl & Beitz, 1996). During this time the design team also often gains insight into the problem through additional research, field observation, review of known standards, interviews, and other means. Once the design team feels that they understand what the client and users need and want, as well as what limitations and restrictions exist in how they go about achieving this, they then move on to generating design possibilities.

In the Generation of Design Alternatives stage of the design process, various brainstorming and other idea generation methods are used to generate innovative and creative solution possibilities (Daly, Christian, Yilmaz, Seifert, & Gonzalez, 2011; Dym & Little, 2009). The success of this step of the design process is strongly correlated with the diversity of thought represented by the brainstorming team, making it advantageous to have teams composed of individuals of various backgrounds and experiences (Post, De Lia, DiTomaso, Tirpak, & Borwankar, 2009). Often to achieve this diversity it is necessary to supplement the design team by adding non-engineers to the mix, including individuals with expertise and experience in the problem at hand.

Once designs are generated, the team moves in to the Design Selection phase of the process. During this phase the design team refines, narrows down, and selects the best idea(s) from the design alternatives (Dym & Little, 2009). To ensure that the design picked is the best to meet the wants and needs of all involved, a design decision analysis is normally performed (Dym et al., 2005). One common way to do this is to use a chart to objectively compare multiple design possibilities based on a set of criteria related to the objectives and requirements of the project (Pugh, 1991). The criteria are generally weighted to indicate relative importance, and each design is then scored on how well it meets each criterion, multiplied by the criteria weight. The weighted criteria scores are then summed for each design, with the highest score being the one most promising to pursue, assuming it meets all the project constraints.

After Design Selection, the design team more fully develops their concept (Dym & Little, 2009). Prior to moving too far forward with it, they will often present the idea to the client, potential users, key stakeholders, and experts in the field to receive feedback, in a process known as a conceptual design review. Based on constructive feedback received, the design team must then determine how to proceed, often returning to earlier stages in the design process.

Once a conceptual design is reviewed favorably, it advances to a more detailed design and a prototype or model is built; then, it is tested in some way to prove feasibility (Dym & Little, 2009). The types of tests that are performed range from computerized models and simulations to focus group and surveys to elicit potential user opinions. Depending on which route of testing the design team chooses, outside individuals and experts in the field may be critically involved to provide quantitative and qualitative feedback about how well the device functions, what problems it has, and what its overall potential is. Following testing, the results and feedback must be critically analyzed by the team to determine the design’s current success.

With sufficient time, design teams then take what they have learned from the testing and revisit earlier stages in the design sequence to revise before proceeding through the process again, iteratively getting closer and closer to a quality end product. In many semester-long classes, however, the process must stop here due to time. Students instead move into the Documentation stage, during which they prepare oral presentations and written reports to convey the entire process they followed in reaching their end conclusion. This stage also includes recommendations for future research.

Gaps in Practice

Though the engineering cornerstone and capstone courses are generally recognized as successful in teaching students the engineering design process (Dym et al., 2005), there are several gaps in practice when it comes to issues related to usability, inclusivity, and accessibility. Three main areas of concern, which serve as the focus of the current research, are:

- The majority of engineering curricula do not well prepare engineering students with the skills to recognize the need for and ability to implement universal design principles into their products.
- Despite a push for diversity in the field of engineering, there remains a need to be more inclusive and make the engineering curriculum more accessible for all students, particularly individuals with disabilities, so that they might fully participate and pursue careers in the field.
- Though the engineering design curriculum has room for, and would benefit from, interactions with a variety of external individuals, these opportunities are not always transparent; qualified and interested individuals may never know about their ability to be involved

These three areas are discussed briefly below.

State of the current engineering curriculum. In the United States, the engineering curriculum is mainly driven by the requirements of the *Accreditation Board for Engineering and Technology* ([ABET]; Felder & Brent, 2003). ABET outlines specific outcome criteria for graduates of accredited programs. Therefore, most institutions structure their engineering curricula, particularly their senior capstone courses, to demonstrate that all criteria have been met prior to graduation (Tooley & Hall, 1999). These criteria, according to the 2010-2011 ABET review process (ABET, 2011), include:

A. an ability to apply knowledge of mathematics, science, and engineering;
B. an ability to design and conduct experiments, as well as to analyze and interpret data;
C. an ability to design a system, component, or process to meet desired needs within realistic constrains such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability;
D. an ability to function on multidisciplinary 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, economic, environmental, 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; and
K. an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

Throughout the years, refinements have been made in the language of the criteria to arrive at their current wording. For example, authors have adapted the more generic criteria *(C) An ability to design a system, component, or process to meet desired needs* (Shuman, Besterfield-Sacre, & McGourty, 2005) to its current form, which elaborates the specific types of constraints that engineering students must consider. This has helped guide engineering curriculum to ensure that topics such as economics, environment, ethics, and sustainability are highlighted in the design process (Dahm & Newell, 2001; Shuman et al., 2005).

The ethics requirement of ABET has helped highlight the role engineers must take to ensure their designs "hold paramount the safety, health, and welfare of the public" (National Society of Professional Engineers [NSPE], 2007). This helps to raise awareness of an engineer's long-term personal responsibility to the end user, but with a focus almost entirely on safety and disaster avoidance. Though the groundwork is partially in place, there are limited efforts to translate this sense of responsibility to ensuring that the designs created are inclusive and ensure equitable use by all.

Though some engineering students, particularly those who will be designing public buildings and structures, are versed in the legal requirements for ensuring accessibility (e.g., Americans with Disability Act [ADA]), the broader topic of universal design receives very little attention in the undergraduate engineering curriculum (Erlandson, Enderle, & Winters, 2006).

Universal design is the act of making spaces, processes–and products–flexible enough to be easily used by the entire spectrum of possible users, without the need for adaptation or specialized design (Zeff, 2007). Though universal design certainly assists individuals with disabilities, it differs from accessibility, as well as assistive and orphan technology, in that the main goal is to make designs more useful *for all* (Welch, 1995). Universal design may not be appropriate for all applications, such as designs that specifically address the proprietary needs of an individual. However, universal design is far more sustainable for most design situations, as it benefits more potential users than other approaches. The guiding principles of universal design are: Equitable Use, Flexibility in Use, Simple and Intuitive, Perceptible Information, Tolerance for Error, Low Physical Effort, and Size and Space for Approach and Use (Story, Mueller, & Mace, 1998; Zeff, 2007). The fundamental principle behind universal design is to design products and environments to respond to the unique nature of all potential users. Since engineering designers create with potential users in mind, there is both opportunity and need for the specific principles and concepts of universal design to be heavily integrated into the design curriculum.

Barriers to increasing diversity in the engineering field. In recent years, there has been a national push to increase diversity in the engineering workforce by increasing the opportunities for females, underrepresented minorities, and individuals with disabilities to pursue engineering as a career (National Science Board, 2004). It is believed that greater diversity will help to sustain and promote innovation (National Science Board, 2004). Current estimates indicate that individuals with disabilities remain poorly represented in engineering fields, with only 1.3% of all individuals with disabilities, and only 0.4% of females with disabilities, working in engineering and architectural professions (Bureau of Labor Statistics [BLS], 2009).

Research has highlighted numerous reasons for the poor representation of individuals with disabilities in engineering careers. Burgstahler (1994) grouped the barriers of individuals with disabilities to pursue careers in science, engineering, and technology in to three categories: Preparation, Access, and Acceptance. The engineering design process is one such example where these issues can play out. For example, the requirement that students work together in a team may heighten issues related to acceptance, while the expectation that students have the prior knowledge and ability to use power tools can limit participation by some individuals with physical or cognitive disabilities (access). Because engineering design is so fundamental to the engineering curriculum, there is a need to ensure that the design curriculum, and especially the design classroom or lab, tries to address these issues to be more inclusive to all.

Involvement of disability services professionals in the design curriculum. As outlined above, the engineering design process includes multiple opportunities to involve individuals from outside the field of engineering, including during the stages of Problem Definition, Generation of Design Alternatives, Conceptual Design Review, and Testing. Engineering programs have begun to build in these opportunities to various degrees. At the University of Dayton, for example, brainstorming sessions in the senior capstone design classes include the design team, project sponsors (clients), any users they would like represented, faculty mentor(s) with expertise in the field, and sometimes other individuals identified by the design team who have prior experience relating to the problem.

In recent years, projects focused on designing for individuals with a disability have emerged (Enderle, 1999). The success of these types of projects requires a strong interface between the engineering design team, professionals in the disability field, and often the specific individual with disability being designed for. Though not necessarily imperative for the project's success, it can also be envisioned that professionals from disability services could provide important insight to *all* engineering teams, in an effort to make any product design more usable for potential users with disabilities. However, many professionals in disability services, especially those working outside of academia, may not be aware of their potential contributions to the engineering design curriculum. These professionals might suggest a project, volunteer to serve as a project mentor, or share resources about disability and universal design. These individuals could serve an important role in educating and raising awareness among engineering students about disability. It is imperative that this occurs on a more widespread scale.

Objective of the Current Research

In an effort to address the need for engineers to be more prepared to design for all, this research study evaluated the implementation and effect of a first-year engineering design course project explicitly focused on universal design. It was hypothesized that students who participated in this project would exhibit clear indications of having considered universal design principles during design selection, as compared to previous projects focused on designing for individuals with disabilities and well-defined "intro to engineering" projects.

The chosen universal design project challenged students to redesign elements in their engineering classroom to ensure a more inclusive environment for all who use, and interact in, the room. This project, therefore, had not only the goal of building awareness and skills related to universal design, but also improving inclusiveness and accessibility of the engineering design curriculum through the ideas and products that were developed. Professionals in disability services, and other individuals with personal experiences relating to diverse needs and abilities, served as class mentors in an effort to establish a possible model for other such partnerships.

Methods

This mixed-methods research was based in the University of Dayton's first-year engineering design course entitled EGR 103 Engineering Innovation, which is described in detail below. A total of 48 first-year engineering students, 24 students per course section, were involved. Students completed either a design project explicitly focused on universal design (as presented to one course section) or a design project focused on designing for individuals with disabilities (as presented to the other section). To compare the effectiveness of each project on increasing student awareness and consideration of usability, inclusiveness, accessibility, and flexibility of design, the decision analysis matrices produced during the Design Selection stage of the engineering design process were quantitatively and qualitatively compared. As a secondary comparison, a similar analysis was performed on a small-scale, well-defined, "intro to engineering" design project that lacked a human-centered focus. Details on all course projects, as well as more information about the data analysis, are presented below. Per the focus of this particular paper, the Universal Design Project is presented in elaborate detail so that it would be possible to be reproduced by others.

Course Structure

EGR 103 Engineering Innovation is a "cornerstone" course to teach the fundamentals of the engineering design and product realization process through project-based learning. It is a two-credit, one semester course required of all first-year engineering students. Multiple course sections, each of approximately 24 multidisciplinary engineering students, are taught each semester, with each section taught by a different instructor. The instructors follow a common course structure, but are given freedom to choose a course project that aligns with their own area of expertise or interest. Projects are intended to address real-world issues, and instructors are encouraged to consider service-learning type projects focused on humanitarian need, sustainability, or assistive devices. For the majority of projects, it is expected that the project be driven by an external partner, such as a local non-profit organization or a local company. This partner, and any other mentors identified by the instructor, serve to help the class throughout the various stages of the design process.

Students are given over 2 months for the project, and work in design teams of approximately four. The class follows the engineering design process outlined at the start of this paper, with a conceptual design review occurring approximately halfway through the project, with time for the design team to receive feedback from class mentors who can attend. Each design team then builds a prototype or model, and concludes the semester by giving a presentation and writing a design report. Though ideas are generally very innovative, because of the underdeveloped engineering skills of first-year students, the built product is not typically developed enough or safe enough to provide an end-product to the client. There is, however, the opportunity for especially promising devices to be pursued in future semesters by upperclassmen or senior design classes.

Project Descriptions

The Universal Design Project. The Universal Design Project was implemented for the first time in one section of Engineering Innovation during Spring 2011. For this project, the instructor approached the University's Director for Student Learning Services, who oversees accommodation for students with disabilities, to serve as the project client.

The Universal Design Project was introduced to the class by first posing a fairly open-ended, ill-defined problem statement about the classroom that the students had been using for the first six weeks of the semester:

> Kettering Labs room 353 (KL353) is a laboratory-based classroom used by many, but certain aspects of it make it difficult to use and maintain efficiently and effectively. We desire to make it more accessible

to all by applying Universal Design principles to solving some of the underlying problems in the room.

Students were then presented a very short description summarizing universal design:

> Universal Design is about improving accessibility and usability of a product, building, or service for all people. Though novice universal designers often start thinking about the design's accessibility with regard to certain populations, such as those with physical disabilities or older users, universal design is best achieved when it is applied by considering the entire spectrum of users when conceiving possible solutions. A driving factor behind Universal Design is that changes that are made to make the product, building, or service better accommodate a certain type of user will often have benefits that carry over into improving usability for all users. For example, a common illustration of Universal Design is the curb cutaways that were originally intended for wheelchair users. Who else benefits from this design feature, however?

To help guide students through preliminary problem definition, a class discussion was held to discuss the classroom space through guiding questions such as (a) Who uses KL353? (b) What do we know about these users? (c) What do we assume about the abilities required for an effective user-environment interaction? and (d) What about the room does not work for you?

At the conclusion of this discussion, which lasted for approximately one hour, a refined problem statement was presented to help those students who were lost at the open-endedness of the project. This included suggesting that students concentrate on one of the following room requirements:

- Ability to meet all users' needs in entering, exiting, and moving about the classroom space
- Ability for all users to sit and work comfortably and efficiently in the classroom space
- Ability to locate, identify, reach, and use equipment, tools, and building supplies
- Ability to read, see, follow, and actively participate in lectures, presentations, demonstrations, experiments, or design building
- Ability to adhere to and ensure safety of all users of the classroom space
- Ability to safely and effectively store supplies and clean the classroom space

During the following class period, a panel of four guest speakers provided additional insight into the problem. All panelists first discussed some of the key points they felt were important and then allowed for question and answer time with the class. The client for the project, the Director of Student Learning Services, spoke about universal design, as well as the needs of some of the students she assists, including students who have used or may use the particular classroom in question. Another guest speaker for the class was a teacher who had been temporarily disabled, and who had taught in the particular classroom while using a wheelchair, then later using crutches. The third guest speaker was a student with an injury requiring the use of crutches, and later a cane, who had used the classroom for the Engineering Innovation course. He shared obstacles he had experienced when working with his team while having limited mobility. A final guest speaker was an engineering student designing an assistive custodial device. This last speaker provided the class insight about considerations that should be taken into account regarding the care and maintenance of the room. This speaker also spoke of personal insights into the psychological effects and frustrations that barriers caused for individuals with disability.

To supplement their learning, all students in the class were also required to find three resources that helped them better understand the problem. These included web-based resources, news articles, academic journals, personal interviews, field observations, etc. Table 1 includes a sample of suggested resources.

The Design for Individuals with Disabilities Project. This project, carried out in a semester previous to The Universal Design Project, asked design teams to develop playground equipment appropriate for installation at baseball parks designed for leagues catering to children with disabilities. Students were challenged to make sure that their designs promote positive interactions between children with disabilities and their peers without disabilities. In this sense, the project had elements of designing for inclusiveness, but focused mainly on designing for persons with disabilities. This focus on individuals with disability was also fostered in the nature of class conversations and research conducted by students.

The Introduction to Engineering Design Project.

Table 1

Sample Web-based References and Resources for Students Learning about Universal Design

Web Resource	Website URL	Summary
Center for Excellence in Universal Design – National Disability Authority, Ireland	http://www.universaldesign.ie	Comprehensive informational site focused on what universal design is, how it is taught, and related standards and guidelines
Center for Universal Design – North Carolina State University	http://www.ncsu.edu/projects/design-projects/udi	Features overview of universal design, relevant publications, examples of past projects, and research
Institute for Human Centered Design	http://www.humancentereddesign.org/index.php	Focus on making all designs more human centered, with a particular emphasis on universal design
Universal Design Education – North Carolina State, University at Buffalo, & Global Universal Design Educator's Network	http://www.udeducation.org	Website to support the teaching and study of universal design through the compilation of numerous resources
Universal Design: Housing Solutions for All Ages and Abilities – The Ohio State University	http://ehe.osu.edu/cs/ud	Site focuses on universal design associated with housing with many examples and videos, as well as educational resources

The smaller-scale Introduction to Engineering Design Project has been used for multiple semesters as a lead-in to the engineering design process. Compared to the large-scale projects detailed above, this project was much more contrived, and well-defined, asking students to design a cardboard table of certain dimensions, using limited materials and time, and being strong enough to support a given weight. No client or potential users were mentioned in the problem definition, though students were given freedom to come up with their own "back-story" and any other additional objectives important to the design team. Students spent approximately three weeks completing the entire design project.

Data Analysis

The instructor used the design decision analysis criteria presented in each team's final project report to quantitatively and qualitatively compare results. In Engineering Innovation, design decision analysis criteria are developed by the students based on the knowledge they gain from the original problem statement and information presented by the instructor, from discussions with the client, mentor, and stakeholders, and through research and any additional resources used. As such, the criteria used in decision analysis indicate what the design team feels is important in identifying "the best" design. The weight given to each criterion conveys the relative importance.

The design decision analysis criteria and their relative weights were first compiled for all six teams for each project separately. These criteria were then reviewed and categorized based on common themes that emerged. These themes, chosen by the instructor to emphasize consideration of universal design principles, included: (a) Criteria that clearly conveyed a correct understanding and recognition of importance of universal design principles, (b) Criteria that conveyed universal design by focusing on accessibility, (c) Criteria that indirectly conveyed universal design knowledge through consideration of functions and requirements, and (d) Criteria related to project feasibility. The average weight of the criteria within each grouping was calculated so that thematic groupings could be compared. Most engineering design groups weighted criteria on a scale of 1 – 10, with 10 being most important, though some teams used a maximum score of 9. However, for the particular semester of the Design for Individuals with Disabilities project, students had not weighted their criteria based on importance, limiting the direct comparisons that could be made.

Results

Analysis of Universal Design Project

For The Universal Design Project, the six design teams used a total of 51 criteria in their decision analyses. Five of the six teams included at least one criterion that clearly conveyed a correct understanding of universal design principles. These criteria are shown in Table 2 and include six directly related principles, and an additional three criteria dealing with functions or features that related to improved usability. The team number is noted in the results table, to demonstrate the fairly even distribution amongst teams. The average weight of importance of these variables was 7.7 ± 1.1 (s.d.), with some students using a maximum importance score of 9, and others 10.

An additional seven criteria were related to universal design, but focused specifically on accessibility. Table 3 shows these measures. The average weight of importance of these criteria was 8.3 ± 1.4 (s.d.), again with some students using a maximum importance score of 9, and others 10.

Though not directly conveying universal design principles, a third category of criteria emerged that demonstrated the students' efforts to apply features, functions, and elements of universal design. These criteria are shown in Table 4. The average weight of importance of these criteria was 6.0 ± 1.8 (s.d.), out of either 9 or 10 (depending on the group).

The last category of criteria that tangentially touched on universal design principles was safety. All six teams included the criteria "Safety" for an average criteria importance weight of 9.29 ± 0.45 (s.d.). An additional team [1] also included the safety-related criteria "Will Not Tip Over" assigning a weight of 5.

The remaining 18 criteria were related to cost, aesthetics, durability, and other less person-centered design criteria. Team 3 was the only team that had all of its eight objectives reflect universal design or human-centered design in some way.

Analysis of Playground for Children with Disabilities Project

A review of the design decision analyses for the project, which asked students to design a playground to be inclusive for children with disabilities, without an explicit focus on universal design, showed differences. Notably, none of the six teams' decision analyses included any criteria that directly reflected principles of universal design, such as flexibility and versatility of use. Similar to the universal design project, however, students did demonstrate a clear focus on accessibility. Five of the six teams included either Accessibility (3 teams), Accessible (1 team), or Wheelchair/Walker Accessible (1 team) as criteria. Additional criteria describing accessibility (Rubber Surface and Avoids Many Levels) were also included.

Additional criteria focusing on the human-centered nature of design, with a particular emphasis on disability, were also evident. For example, after learning that children with autism often benefit from tactile feedback, several design teams chose to include "Texture" as a criterion in their design decision analysis. Table 5 shows those criteria that fit this theme. As with the Universal Design Project, safety was a criterion for all teams.

Analysis of Cardboard Chair Project

In contrast to either of the other two projects, the criteria used for the decision analysis of the cardboard chair concentrated almost entirely on functions and features, without any emphasis on users. Of 35 criteria used by the six teams, the only criteria that conveyed consideration of people, in some way, were: (1) Safety (2 teams), (2) Prior Experience, (3) Build Difficulty, and (4) Meets Clients Demands. In these rare cases, the emphasis was placed on the design team, or the design request. Only safety, noted by two of the six teams, referred back to the users.

Analysis Summary and Comparison

Comparison of the three projects showed that

Table 2

Summary of Design Decision Analysis Criteria that Clearly Conveyed a Correct Understanding and Recognition of Importance of Universal Design Principles

Student Defined Criteria	Weighted Criteria	[Team]
Universal Design	10	[5]
Avoids Setting People Up for Failure	8	[1]
Easy for All to Use	8	[3]
Feeling of Equality	7	[6]
Versatility	7	[5]
Obvious Use	6	[2]
Versatile Height	8	[3]
Easy to Move by All	8	[3]
Doesn’t Inhibit Ability to Reach Storage	7	[3]

Table 3

Summary of Design Decision Analysis Criteria that Conveyed Universal Design by Focusing on Accessibility

Student Defined Criteria	Weighted Criteria	[Team]
Accessible	10	[6]
Universally Accessible to Handicap	9	[2]
Accessibility	9	[4]
Accessible to Many People	9	[1]
Group Accessible	8	[6]
Wheelchair Accessible	7	[3]
Value for Non-Handicapped too	6	[2]

Table 4

Summary of Design Decision Analysis Criteria that Indirectly Conveyed Universal Design Knowledge through Consideration of Functions and Requirements

Student Defined Criteria	Weighted Criteria	[Team]
Better Workspace for Individual Work	9	[3]
Moves Up and Down	7	[1]
Movable	7	[6]
Opens Up Floor Space	6	[3]
Maximize Space	6	[4]
Easy to Clean	6	[4]
Maneuverability	6	[4]
Comfort	6	[5]
Weight	5	[6]
Easy to Use	2	[1]

safety was consistently viewed as one of the most important considerations for engineering design, being the only criteria category to be represented in all three projects. For the larger projects, safety was the only criteria that every team included in their decision analysis, and when weighted received the highest average importance, 9.29 ± 0.45.

Accessibility criteria were next most commonly represented. They were incorporated into the decision analyses of 5 of 6 teams for each of the large projects, and had an average score of weighted importance of 8.3 ± 1.4.

Criteria relating to the application of universal design principles to the design were only present in the decision analyses of the Universal Design Project. These criteria were present for 5 of the 6 teams and accounted for almost 18% of the total number of criteria. These criteria received an average weighted importance of 6.0 ± 1.8. Additionally, there were another 10 criteria (about 20% of total responses) that indirectly conveyed universal design knowledge through consideration of functions and requirements.

Though no criteria directly or indirectly related to universal design were included in the decision analyses for the playground project, a new set of criteria related to consideration for the needs of individuals with specific disabilities was included.

Discussion

Raising Awareness of Universal Design

Results suggest that the Universal Design Project was successful in helping engineering students consider the importance of designing for inclusivity in their projects, supporting the study hypothesis. The majority of criteria used in the design teams' decision analyses reflected consideration of the end user, with many criteria directly reflecting universal design principles. This was especially notable, as there was very limited formal education about universal design, leaving students to draw only from their own research and the guest panel presentation. Though it is clear students were able to draw many parallels, a more

Table 5

Summary of Design Decision Analysis Criteria for Playground Project Indicating a Focus on the Disability

Student Defined Criteria	[Team]
Texture	[1]
Shade Provided	[1]
Building Skills	[1]
Encourages Survival Skills	[2]
Variety of Textures	[2]
Contains Sensory Stimulus	[4]
Avoid Crazy Patterns	[4]
Encourages Social Interaction / Teamwork	[2]
Physically Interactive	[6]
Educationally Interactive	[6]
Socially Interactive	[6]
Educational	[2, 4, 5]

structured lesson on the topic may have led to more refined design decision criteria. For example, the inclusion of the seven guiding principles of universal design (Story et al., 1998) in a targeted lecture may have contributed to identifying design criteria that were more clearly related to universal design principles. Similarly, revisiting the project description to better emphasize certain aspects of design (e.g. flexibility of use) and de-emphasizing others (e.g. accessibility and disability) may have helped better guide students.

Results are especially promising in comparison to the two other types of projects considered. The project posing the challenge of designing a playground where children with disabilities can interact with their peers without disabilities had the potential to include a very strong emphasis on universal design. Even without the explicit focus on universal design principles, there was still opportunity for students to include criteria that would have reflected the inclusive nature that their playgrounds were aiming for. Had they done so, students would have unknowingly incorporated elements of universal design. This, however, was not the case. These findings suggest that universal design knowledge does not happen naturally, and that students do not inherently think in these ways. As such, this further promotes the need to find ways to explicitly emphasize universal design in the engineering curriculum.

Results of both the Universal Design Project and the Playground for Children with Disabilities Project did support, as suggested in the introduction of this paper, that students do seem to have heightened awareness of issues related to accessibility. In fact, in the Universal Design Project, students rated accessibility-related criteria as more important, on average, than the criteria related to universal design principles. Though the recognition of accessibility is clearly important, it may hinder students from looking at the broader scope of the importance of designing for all. As such, there may be a need to begin to better delineate universal design from accessibility, as proposed by Welch (1995).

Similarly, it is clear that students have some ability to cater their designs to ensure they meet the specific needs of individuals with disabilities. Though this is a good start, products developed according to the seven guiding principles of universal design would not only encompass these needs, but have additional favorable outcomes. It appears that, to develop engineers who have a universal design mindset, it is important that design instructors de-emphasize the need to design specifically for individuals with disabilities. In fact, designing for an individual with a disability in mind, which is growing in popularity in the engineering curriculum, often leads to designing specialized assistive devices, which contradicts the driving forces of universal design.

In contrast to the other two projects, the Cardboard Chair Project used to introduce students to the engineering design process, not surprisingly, did very little to get students to consider the human-centered nature of design. This is likely due to the fact that the project was not "real-world" in nature, and was not presented in the scope of a specific client or group of users. This is somewhat of a concern, as these types of contrived problems are often used to introduce young engineers to engineering design. Though they may achieve this goal, results suggest that they do little to promote the important skill of considering the end user. In fact, only two of six teams even considered safety in their design.

These results have implications for teaching engineering students to be more inclusive in their design thinking. It appears that projects with an explicit universal design focus do raise student awareness on these topics. In the course where the project was framed around universal design, it was promoted to students as a type of skill set that they could take on to future design projects. It is unclear, though, how well this knowledge will translate to future projects where the focus is not specifically universal design in nature. Future work should seek to evaluate the effect of this type of project on future design decision analyses. It may also be beneficial to determine whether a full project, such as described in this paper, is necessary to raise student awareness on the issues, or whether lectures on universal design to all students is sufficient. Regardless, it was observed that even when the project lends itself to universal design considerations, such as the Playground for Children with Disabilities Project, students do not think in this mindset without universal design having been promoted. This suggests that universal design knowledge is not inherent in engineering students and does need to be taught in some way. The Universal Design Project is one model to achieve this.

Student reactions to the Universal Design Project were mixed. Two teams did a very good job of demonstrating a much higher level thinking of universal design principles than the rest of the class. For example, one team designed a table that was accessible for a range of people, including individuals who were pregnant or obese, but also showed how the tables could be arranged in different ways to emphasize either group work or small group teacher-led instruction. This demonstrated that they had clearly understood the idea of accommodating for all, as well as designing products that could be flexible and used in multiple ways and situations. Another group designed modular tables, each fully adjustable, arguing that this approach circumvented the assumption that everyone is the same. Instead, the tables were specifically designed to show that each individual was unique and had different preferences.

Some of the students in the class seemed to enjoy the project. Further, they recognized that, by carrying it out, they had developed a new skill set that could help them be more successful designers in the future. Other students, however, did not especially like the scope of the project. This may have been related to the fact that most of the students chose to focus on building tables and workspaces for the Universal Design Project, even after having built the cardboard tables for the previous project. This choice was despite the latitude students were given to design anything, from more adaptable tools to more user-friendly storage systems. Students claimed that listening to the guest panel led them in the direction of tables and workspaces. This was disappointing to them, because they had already done a table for the first project, and it meant everyone was doing something fairly similar.

Aim for Increased Usability and Inclusiveness of Classroom Lab Space

The majority of the design prototypes were not fully functional because of the less sophisticated technical background of the first-year students. As such, the project did not result in any readily implementable means of improving the classroom space to be more inclusive of all of the potential students who might use the space. However, some of the design ideas that were presented by the design teams were appropriate and achievable solutions for increasing the usability of the classroom, if further refined or more professionally built. Interestingly, five of the six teams designed tables and workspaces. It had been hoped that a broader range of designs would be developed, but these common designs did meet the important need to ensure equality of all team members in design classes, where meeting and work is generally done around a central workspace.

Involvement of Professionals in Disability Services

This project demonstrates the role that professionals in disability services fields, individuals with disabilities, and other key stakeholders can play in the engineering design process. In the case of the Universal Design Project, as is often the case, the information conveyed by the guest panel was invaluable. Additionally, feedback received during the conceptual design phase of the project was also beneficial, though the majority of class mentors could not attend due to scheduling conflicts. Professionals interested in participating in such a project should be aware that many engineering programs have an office dedicated to engineering design curriculum, staffed by an individual in charge of directing senior capstone design courses. First-year engineering design classes are often run through this office. As a first step to becoming involved, interested individuals can contact the engineering design office at their institution, and express their interest, background and expertise, any project ideas, and ways they envision helping. Even if an immediate need does not exist, because of the variety of projects that come up, there may likely be an opportunity in the near future. Individuals knowledgeable in universal design might also be in a position to offer a guest lecture for all engineering classes.

For those individuals who do wish to get involved in engineering design projects, it is important to remember that a key to the success of the project is to systematically narrow down the originally posed open-ended problem. As such, it is not as beneficial to those involved if course mentors propose well thought-through, narrowly defined problem or problem solutions. Rather, keeping answers and information open-ended can help lead students into design generation that is not limited or confined, and that promotes innovation. This type of guidance is, therefore, ultimately mutually beneficial.

Opportunities for involvement will likely increase as more formalized human-centered design efforts grow. Lande and Leifer (2009) have shown how design clinic projects have begun to shift focus from manufacturing, tools, and products, to projects that emphasize the person who will use the product (i.e., human-centered design). With this shift has come increased efforts to better interact with potential users who have insight into design needs, as well as ways to document this new knowledge (Roschuni & Agogino, 2011). As such, there will be increased need for diverse users, including individuals with disabilities, and individuals in the disability services profession to participate in interviews, ethnographic studies, and other means of sharing experiences. This will enable better designs and richer student experiences.

Conclusion

In conclusion, this research project shows that students do not implicitly consider universal design principles in designing products, even when these products are to be used by a diverse user group. The use of a specific universal design project did demonstrate that students were largely able to understand, and correctly apply, the principles of universal design to maximize the inclusivity of their designs. Though it is currently unclear how this knowledge translates to projects that are not specially focused on universal design, it is clear that there is a need to introduce and promote universal design in the curriculum in some way, with the project described as one possible model. Involvement of disability professionals, individuals with disabilities, and other key stakeholders is invaluable to enhancing the engineering design process and preparing engineers who are more cognizant of the needs to design for inclusivity.

References

Accreditation Board for Engineering and Technology. (2011, May 28). *Criteria for accrediting engineering programs, 2010-2011 review cycle*. Retrieved from http://www.abet.org/uploadedFiles/Accreditation/Accreditation_Process/Accreditation_Documents/Archive/criteria-eac-2010-2011.pdf

Bureau of Labor Statistics. (2009). Persons with a disability: Labor force characteristics – 2009. *USDL-10-1172*. [News Release]. Retrieved from http://www.bls.gov/news.release/disabl.nr0.htm

Burgstahler, S. (1994). Increasing the representation of people with disabilities in science, engineering, and mathematics. *Information, Technology and Disability, 1*(4). Retrieved from hhttp://www.washington.edu/doit/Press/representation.html

Dahm, K., & Newell, J. (2001). Baseball stadium design: Teaching engineering economics & technical communication in a multi-disciplinary setting. *Proceedings of 2001 American Society of Engineering Education Conference & Exhibition, Session 1339.*

Daly, S. R., Christian J., Yilmaz S., & Seifert C. M. (2011). Assessing design heuristics for idea generation in an introductory engineering design course. *Preliminary Proceedings of Mudd Design Workshop VIII.*

Dutson, A. J., Todd, R. H., Magleby, S. P., Sorensen, C. D. (1997). A review of the literature on teaching engineering design through project-oriented capstone courses. *Journal of Engineering Education, 86*(1), 17-28.

Dym, C. L., & Little P. (2009). *Engineering Design: A Project-Based Introduction* (3rd ed.). Jon Wiley & Sons.

Dym C. L., Agogino A. M., Eris, O., Frey, D. D., & Leifer, L. J. (2005). Engineering design thinking, teaching, and learning. *Journal of Engineering Education, 94*(1), 103-120.

Enderle, J. D. (1999). An overview of the National Science Foundation program on senior design projects to aid persons with disabilities. International *Journal of Engineering Education, 15*(4), 288-297.

Erlandson, R., Enderle, J., & Winters, J. (2006). Educating engineers in universal and accessible design. In J. M. Winters & M. F. Story (Eds.), *Medical instrumentation: Accessibility & usability considerations.* CRC Press.

Felder, R. M., & Brent, R. (2003). Designing and teaching courses to satisfy the ABET engineering criteria. *Journal of Engineering Education, 92*(1), 7-25.

Lande, M., & Leifer, L. (2009).Classifying student engineering design project types. *Proceedings of the 2009 American Society of Engineering Education Pacific Southwest Regional Conference,* 13 – 19.

National Science Board. (2004). Broadening participation in Science and Engineering: Workshop proceedings. [National Science Board Workshop] *National Science Foundation.* Retrieved from http://www.nsf.gov/pubs/2004/nsb0441/nsb0441.pdf

National Society of Professional Engineers. (2007). *Code of ethics for engineers*. Publication #1102. Retrieved from http://www.nspe.org/resources/pdfs/Ethics/CodeofEthics/Code-2007-July.pdf

Pahl, G., & Beitz, W. (1996). Engineering design: A systematic approach. London, England: Springer-Verlag.

Petroski, H. (1994). *The evolution of useful things: How everyday artifacts – from forks and pins to paper clips and zippers – came to be as they are.* New York, NY: Vintage Books.

Petroski, H. (2004). *Small things considered: Why there is no perfect design.* New York, NY: Vintage Books.

Post, C., De Lia, E., DiTomaso, N., Tirpak, T. M., Borwankar, R. (2009). Capitalizing on thought diversity for innovation. *Research-Technology Management, 52*(6), 14-25.

Pugh, S. (1991). *Total design: Integrated methods for successful product engineering*. Addison-Wesley.

Roschuni, C., & Agogino, A.M. (2011). Communicating design research: Framing techniques. *Preliminary Proceedings of Mudd Design Workshop VIII.*

Schuman, L. J., Besterfield-Sacre, M., & McGourty, J. (2005). The ABET “professional skills” – Can they be taught? Can they be assessed? *Journal of Engineering Education, 94*(1),41-55.

Story, M. F., Mueller, J. L., & Mace, R. L. (1998). *The universal design file: Designing for people of all ages and abilities*. Raleigh, NC: Center for Universal Design, North Carolina State University.

Tooley, M. S., & Hall, K. D. (1999).Using a capstone design course to facilitate ABET 2000 program outcomes. *Proceedings of the 1999 American Society of Engineering Education Conference & Exhibition*, Session 1625.

United States Department of Justice Americans with Disabilities Act. (2011, May 30). A*DA Design Standards*. Retrieved from http://www.ada.gov

Welch, P. (Ed.). (1995). *Strategies for teaching universal design*. Berkley, CA & Boston MA: Adaptive Environment & MIG Communications.

Zeff, R. (2007). Universal design across the curriculum. *New Directions for Higher Education*, *137*, 27-44.

About the Author

Kimberly Bigelow received her BS degree in engineering mechanics from Michigan State University and MS and Ph.D. in mechanical engineering with a focus in biomechanics from Ohio State University. She is currently an assistant professor in the Department of Mechanical and Aerospace Engineering and directs the Engineering Wellness and Safety Lab. Her research interests include engineering design education and clinical biomechanics. She can be reached by email at: Kimberly.Bigelow@udayton.edu

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