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Engineering Hope: Enhancing Quality of Life through Design Education

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Introduction

Providing engineering students with challenging and meaningful design experiences is necessary to prepare students to function as professional engineers. Engineering design courses focused on creating and fabricating assistive technology products for individuals with disabilities have become increasing common over recent years [1-3]. This paper describes an innovative teaching approach through which engineering students and doctor of physical therapy (DPT) students came together to design and build a power mobility device that allows young children with severe motor, cognitive, and communication deficits the opportunity to move and explore their environment in a safe and effective manner.

Engineering Course Overview

Within the engineering design course at our University, concepts related to needs analysis and problem definition; design criteria and critical parameter identification; and consideration of alternative solutions are taught using methods based upon the Design for Frontier Concepts method [4-6]. Instruction emphasizes the students' understanding of the engineering problem within the real-life context of the product user (e.g., the circumstances or setting in which product will be used). This contextual needs assessment is posed to assist the engineering design team to uncover the "how," "where," and "who" factors of the product's context and includes factors related to the intended use of the product (the environment, duration of use, etc.), the intended product user (user needs, values, and abilities), and the intended market (competing products for instance). Such methods have been found to be particularly beneficial when design problems fall outside of the typical experience and expertise of the student design team [4-6]. Once the basics of the Design for Frontier Context [4-6] are presented to students, an open-ended instructional method that highlights the process of design versus the product of the design process is used to facilitate student engineering roles and to promote independent problem solving skills.

While this course is intended to prepare students to meet Student Outcomes a-k under the General Criteria for Baccalaureate Level Programs as outlined by the Accreditation Board for Engineering and Technology's (ABET) [7], the course is structured to primarily target Student Outcomes c, d, e, g, and k [7]. Specific course objectives related to these Student Outcomes are as follows:

1. Students will be able to follow a structured process to design, prototype and test a solution to meet the customer requirements. (ABET Student Outcomes: c, d, e, k [7])
2. Students will be able to generate feasible alternative solutions and select the best solution. (ABET Student Outcomes: c, e, k [7])
3. Students will be proficient in communicating the results of their design work in written and oral formats. (ABET Student Outcome: g [7])

Project Description

To achieve the aforementioned objectives and outcomes, students are presented with various engineering problems to solve through a team design effort. For this particular project, a faculty member from physical therapy presented the class with the need to develop a power mobility device that would give young children with severe motor, cognitive, and communication deficits the ability to move and explore their environment in a safe and effective manner. As background to the project, the physical therapist explained to the class that young children with these multiple, severe deficits are limited in their ability to use self-initiated movement to explore and learn from the world around them. Such children are often dismissed as either too young or too physically involved to use power mobility [8-11]. If a trial of power mobility is attempted, simple, readily available power mobility options such as adapted ride-on-toys do not provide these severely involved children with the external support necessary for them to safely and effectively use a joystick or switch to control the mobility device. Given that self-initiated locomotion is critical to the development of numerous cognitive, perceptual, and social skills, young children who are unable to move and explore their environment may not gain the skills necessary to maximize development in these essential areas of function [8-11]. Faculty from engineering and physical therapy thus felt that a device was needed to allow these children to safely explore their environment.

To address this design problem, a student engineering team composed of both undergraduate and graduate students from the Mechanical Engineering, Electrical Engineering, and Product Design and Manufacturing Programs was tasked to work with DPT students to design and build a power mobility device that would meet the unique needs of these young children with severe motor, cognitive, and communication deficits. Although primary instruction for the engineering students was provided by an engineer, faculty from both engineering and physical therapy worked together to provide guidance and mentoring to the project design team.

Instructional Processes

The design course outlined above followed a rigorous design process beginning with the Contextual Needs Assessment method developed by Matthew Green of LeTourneau University [4-6]. As part of this methodology, the engineering students began the project by employing a structured questioning method as outlined below in Table 1 to help them to understand the engineering problem within the real-life context of the product user.

Table 1. Product design context categories from Green et al [4-6]

Category	Sample Context Factors
HOW Application Context	• Application task • Usage frequency • Transportation mode • Etc.
WHERE Environment Context	• Infrastructure (e.g. energy & cost) • Weather and climate • Maintenance and parts availability • Etc.

WHO Customer Context	• Physical Abilities • Skills and education • Cost expectations • Etc.
MARKET	• Features of available products • Performance and quality of available products • Cost of available products • Etc.

From the onset of the project, the engineering and DPT students appeared to approach the design problem from different perspectives. The DPT students were focused on the needs and abilities of children who might be using the device. The engineering students were much more focused on the technology available to solve the design problem. The DPT students all had previous hands-on experiences working with young children who have special needs. With the exception of one parent in the group, the engineering students had very limited experiences with typically developing children and no experience interacting with children who have severe motor, cognitive, and communication deficits.

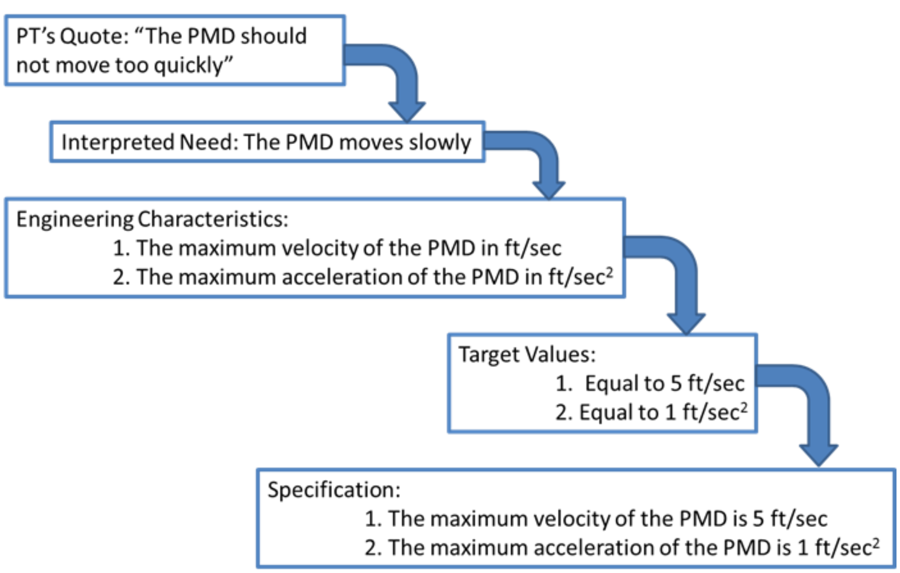
To help the engineering students to better understand the context of the engineering problem, hands-on interactions with specific children targeted to use the prototype were implemented. Individual children with special needs and their parents were invited to come to the University to meet with engineering students. The DPT students and the physical therapy faculty member facilitated these hands-on sessions. Engineering students observed the children partaking in physical therapy interventions and performing functional tasks such as attempting to hold up their head, sit, or walk with assistance and support from the physical therapist. The engineering students were encouraged and prompted to interact with the children during these sessions and were asked to participate in play activities (such as singing children's songs, assisting the children in manipulating simple toys, or blowing bubbles). Once the engineering student and the child had gotten a chance to know each other, the physical therapist instructed the engineering student to safely hold and support the child for play activities. During these hands-on activities, the engineering students learned about the amount of external support that each of the children needed to be able to sit and still use their hands. Engineering students also felt first-hand the degree of muscle stiffness (muscle tone) that these children often have in their arms and legs coupled with poor head and trunk control that is typically found in these children. Although these sessions often focused on the difficulties that these children must overcome to be able to sit in a device and use power mobility, the engineering students also had the opportunity to directly observe each child's capabilities and unique personality.

During these hands-on sessions with the children, the engineering students also interacted with the children's parents. Parents shared not only their views related to their perceptions of the difficulties that their child must overcome to be able experience self-locomotion in a power mobility device, but their views as to the need for such a device and how their child might benefit from such a device. During these interactions, the parents often shared their personal stories related to being a parent of a child with special needs and described both the joys and challenges they had experienced. These interactions with parents also included time for the engineering students to ask the parents questions related to the contextual needs assessment for the product (the "how," "where," and "who" factors).

To further assist the engineering students to appreciate the importance of understanding the context of the engineering problem and the need to work in partnership with the DPT students, faculty from engineering and physical therapy actively sought to model interprofessional collaboration. The engineering faculty member often participated in the hands-on sessions with the children. For example, if the engineering students appeared reluctant to ask the DPT students in-depth questions concerning a child's diagnosis and medical history, the engineering faculty member would initiate a line of questioning to help uncover this information. The engineering faculty member would also interact with the child and family and hold the child during the session to model respectful exchanges with the child and family. During design meetings, if the DPT students were not asking the engineering students to fully explain engineering concepts (the merits of brushless versus brushed motors for example), the physical therapy faculty member would initiate a series of questions that required the engineering students to explain concepts in lay-language. When the engineering and DPT students disagreed about a specific aspect of the product design, the engineering and physical therapy faculty members demonstrated how these disagreements could be resolved by examining each student groups' understanding of the context of the engineering problem and finding common ground by which to resolve the issue.

Once the engineering students gained a better understanding of the children and their needs, the engineering students and the DPT students worked to develop specifications for the device. Differences were again apparent in the ways that the engineering and DPT students appeared to approach the design problem. For example, the DPT students stated that the power mobility device "should not move too quickly". The engineering students documented this need area and then asked the DPT students "How many feet per second should the power mobility device be able to move?" The concept of movement speed in feet per second was not something that the DPT students were able to easily conceptualize. To solve this problem, students from each group investigated the mean walking speed of typically developing young children and set out to demonstrate these speeds for the group. Using this method as shown below in Figure 1, the DPT students and the engineering students were able to problem solve ways to determine a range of safe speeds for the device.

Figure 1. From DPT Student statement to engineering specification



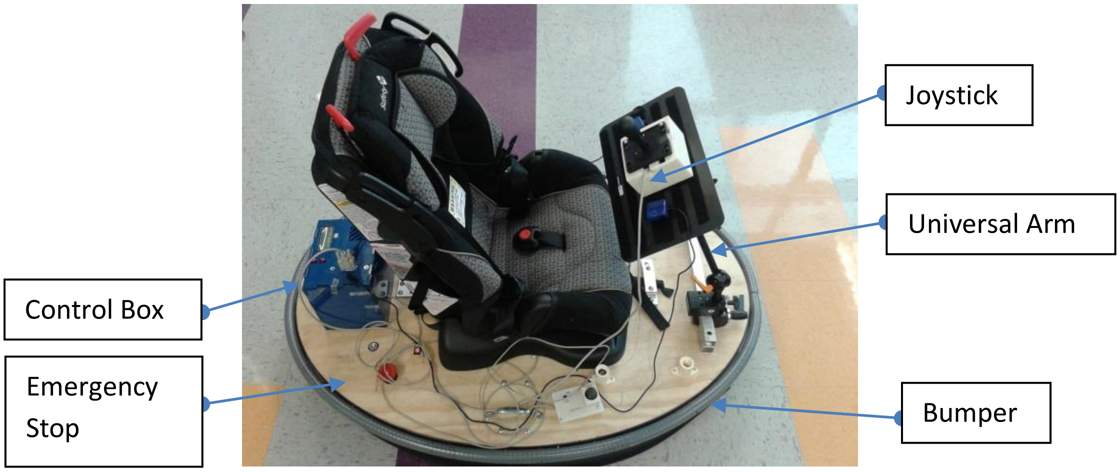
Throughout the design process, engineering students were encouraged to present initial design concepts and ideas to the DPT students and the physical therapy faculty as well as to the parents of children with special needs. By soliciting frequent feedback from these various stakeholder groups, unforeseen problems were able to be solved before the design was finalized. For example, both the DPT and engineering students had assumed that the device would be used primarily in large spaces with linoleum floors with very few obstacles. Feedback from the parents and physical therapy faculty lead the students to realize that the device could potentially be used on carpeted surfaces and in homes or pre-school settings that had lots of obstacles on the floor. These realizations helped the engineering students to reconsider factors related to acceleration, maneuverability, and overcoming potential friction of different surfaces.

After an initial prototype of the power mobility device was constructed, the physical therapy faculty member invited a child who was known to be skilled in the use of power mobility devices to come to the University and test the device. It was surmised that since this child was known to be a community user of power mobility that any problems that the child had driving the device would be related to the device and not the child. During the session with this child, the DPT students were able to assist the engineering students in discovering the aspects of the device that were working well for the child and those aspects that were hindering the child from achieving his typical level of skilled driving in a power mobility device. For example, the DPT students noted that the tray holding the joystick to operate the power mobility device did not adequately support the child's arm when he was operating the joystick and lead to the child's rapid fatigue. It was also noted that the joystick was not able to be optimally positioned to meet the child's specific access needs. Since these factors were identified early enough in the design process, these issues were addressed in the final prototype of the project device.

Project Outcomes

The Play and Mobility Device that emerged from this design project is shown below in Figure 2. This device allowed the faculty members from engineering and physical therapy to further collaborate to begin exploring the potential impact of training with such a device on quality of life and the emergence of beginning power mobility skills in young children who have severe motor, cognitive, and communication deficits. Preliminary data collected in individual cases as been promising and a formal research study focused on use of the Play and Mobility Device is currently being planned.

Figure 2. The Play and Mobility Device



When considering the potential benefits of having engineering students and DPT students work together on this design project, both the engineering faculty member and the physical therapy faculty member anticipated that the interprofessional nature of the project would enhance the students' development of communication and teamwork skills within the design process and challenge both groups of students to leave their professional silos in ways that facilitated collaboration to solve the design problem. While these benefits were realized, what the faculty members did not expect was the learning that the engineering students appeared to experience beyond the confines of the design process itself. For example, the engineering students appeared gain knowledge not only about the needs of children with disabilities but also about the capabilities of these children. They appeared to begin seeing these children not as children who were vastly different from typically developing children, but as individual children who, like all children, have needs, abilities, strengths, hopes, and dreams. Written reflections from the engineering students revealed the following comments:

> "When I saw (the child's name) try out the Play and Mobility Device, it was wonderful to see the smile on her face." - Biomedical Engineering Student

> “I learned that children with special needs can also develop gradually …and interact with their environment..” – Biomedical Engineering Student

> “It is amazing to see the children learn (how to drive and explore) in only a short amount of time using this device.” – Product Design and Manufacturing Student

The engineering students also appeared to gain an understanding of the needs, concerns, and desires of the parents and family members of children with special needs. Written reflections from the engineering students revealed the following comments:

> “ One (of the things I) learned from working on this project (was the) willingness (of the parents) to try new things (and the lengths) that the parents will go to see their child succeed.” - Product Design and Manufacturing Student

> “(When the child was using the device), (the child) wasn't the only one smiling, her sister and parents were also full of joy…” - Biomedical Engineering Student

> “I felt the (parents’) concern….for (their child’s) safety and control requirements during movement. - Biomedical Engineering Student

> “(When the child was using the device), it was like (the child) and her twin sister were able to play together for the first time.” - Biomedical Engineering Student

The engineering students also appeared to learn the potential impact that engineering can have on the lives of individuals. Being able to offer these children a means by which to move and seeing the joy that this movement brought to these young children helped the students to feel that they made a difference to improve the children’s quality of life and unexpectedly helped to achieve ABET Student Outcome j in that the engineering students gained knowledge of the impact of engineering technology solutions in a societal context. Written reflections from the engineering students revealed the following comments:

> "As an engineering student, seeing your projects being used to help people is a truly empowering experience and I'm so glad to have had that opportunity. Engineering is more than just building stuff - it's about making people's lives better." - Biomedical Engineering Student

> "At the beginning of this project, I did not expect to have this big of an impact on these children's lives. Now that I've been involved in more than just building the device, I've been able to see these remarkable improvements. The work we've done truly does have an amazing impact on these children's lives. It's been an awesome opportunity to see the joy on these children's faces as they use the device…." - Product Design and Manufacturing Student

Discussion

This paper has described an innovative teaching approach through which engineering students and DPT students came together to design and build a power mobility device for young children with severe, multiple deficits. Although the Design for Frontier Concepts method [4-6] provided a systematic approach to successfully guide the engineering students through the design process, implementing these Frontier Concepts posed certain challenges. The process of applying this method requires an investment of time, energy, and effort from students, faculty, and potential users. Both the engineering students and the DPT students appeared to want to jump right into designing the power mobility device and seemed to feel initially that the time spent understanding the context of the problem as outlined by the Frontier Concepts [4-6] was "busy work". Although students from both groups appeared to enjoy the hands-on interactions with the children with special needs, the engineering students initially questioned the need to interact with multiple children with special needs. Typical of novice designers, the engineering students wanted to move forward with the "real work" of the design process and thought they could fully understand the problem based on their interactions with a single child. Encouraging the engineering students to more fully understand the context of the problem and engage in multiple hands-on interactions with different children ultimately appeared to benefit the design process as interactions with each different child brought about new insights into the context of the use of the device and new discoveries. For example, what if the child required a ventilator to breathe? How would this ventilator be secured on the power mobility device? What if the child was unable to use their hands to access a joystick or switch? How could the power mobility device be designed to allow a child to use a head switch or a foot switch? Without the multiple hands-on interactions, it is doubtful that the engineering students would have been able to successfully design and build a device to meet the potential needs of a variety of children with special needs.

Conclusion

Although faculty from engineering and physical therapy expected that the opportunities for interactions with children and families and for communication with other professional students would assist in achieving ABET Student Outcomes c, d, e, g, and k [7], the engineering students appeared to learn more than just the design process. The hands-on nature of this project appeared to maximize the engineering students' understanding of the context of the engineering problem. Using the Design for Frontier Concepts method [4-6], the engineering students came to realize that real-life problems are not the same as paper problems in a book: a child with special needs is not an equation to solve but a person whose quality of life can be dramatically impacted by engineering and the design process.

The engineering students appeared to benefit from stepping out of their comfort zone to interact with and learn from children who have special needs. Being able to offer these children a means by which to move and seeing the joy that this movement brought to these young children helped the engineering students to feel that they made a difference to improve the children's quality of life. Perhaps most importantly, the engineering students were able to recognize that engineering and the design process provided these children with special needs with more than just a means by which to move and explore: engineering was able to provide these children and their families with hope.

References:

1. Goldberg, M.R. and Pearlman, J.L. *Best Practices for Team-Based Assistive Technology Design Courses*. Annals of Biomedical Engineering, 2013. 41(9): p. 1880-1888.
2. Catalano, J. D., P. Wray, and S. Cornelio. *Compassion practicum: a capstone design experience at the United States Military Academy*. Journal of Engineering Education, 2000. 89(4): p. 471–474
3. Enderle, J. D. *An overview of the National Science Foundation program on senior design projects to aid persons with disabilities*. International Journal of Engineering Education, 2000. 15(4): p. 288–297
4. Green, M. G., J. S. Linsey, C. Seepersad , K. Schmidt, and K. L. Wood. *Design for Frontier Environments: A Novel Methodology and Results of Classroom Integration.* Proceedings of the 2006 American Society for Engineering Education Annual Conference, Chicago, IL, 2006
5. Green, M.G., D.J. Jensen, C. C. Seepersad, and K. L. Wood. *Design for Frontier Contexts: Classroom Assessment of a New Design Methodology with Humanitarian Applications*. International Journal of Engineering Education, 2009. 25(5): p. 1029-1045
6. Green, M. G., J. S. Linsey, C. C. Seepersad and K. L. Wood. *Enabling Design in Frontier Contexts: A Contextual Needs Assessment Method with Humanitarian Applications*. Proceedings of the 2006 American Society of Mechanical Engineering International Design Engineering Technical Conferences, Philadelphia, PA, 2006.
7. Accreditation Board for Engineering and Technology. Criteria for Accrediting Engineering Programs, 2014 – 2015. 2013 [cited 2013, December 29]; Available from http://www.abet.org/eac-criteria-2014-2015/
8. Jones, M.A., I. R. McEwen, and B.R. Neas. *Effects of power wheelchairs on the development and function of young children with severe motor impairments*. Pediatric Physical Therapy, 2012. 24(2): p. 131-140
9. Nilsson, L.M. and P.J. Nyberg. *Case report—driving to learn: a new concept for training children with profound cognitive disabilities in a powered wheelchair*. American Journal of Occupational Therapy, 2003. 57(2): p. 229–233
10. Nilsson, L.M., and H. Thulesius. *Driving to learn in a powered wheelchair: the process of learning joystick use in people with profound cognitive disabilities*. *American Journal of Occupational* Therapy, 2011. 65(6): p. 652–660

11. Butler, C. *Effects of power mobility on self-initiated behaviors of very young children with locomotor disability*. Developmental Medicine and Child Neurology, 1986. 28(3): p. 325-332