How Consideration of Disability Improves Interactive Innovation in Engineering Education

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Matthew Evanko

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On my honor as a University student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments.

Signed: ____ Date ____________________
Matthew Evanko

Approved: ____ Date ____________________
Kathryn A. Neeley, Associate Professor of STS, Department of Engineering and Society

Introduction

"Engineering has always been a liberating force" (Bejan, 2018, p. 43). At the heart of engineering is the drive to create constantly improving technology that makes lives easier and better for all people. Technology aimed at helping those with disabilities is one of the most important categories of innovation, as wheelchairs and similar assistive devices have allowed for more freedom and independence for disabled persons. However, disability is often left out of engineering education, leaving an important angle for engineering insight unexplored.

For my technical project, our group designed and built a human powered vehicle that requires pedaling. After personal injuries made several team members unable to use the bike, we saw that this was a larger problem in the design of both our product and many others. Research showed that this was already being addressed in the growing industry of ride sharing, as groups worked to include disabled people with accessible bikes. The engineers behind bike sharing failed to consider the various levels of mobility of potential users, and the users then had to advocate for changes themselves (Zaveri, 2018, n.p.).

A growing movement in activism for disabled people argues that "physical disability isn't a property of a person, it is a property of a person together with an environmental situation" (Noë, 2015, n.p.), or to say that a disabled person is not lacking, they merely fail to work within society as it has been made to work for the average person. Because their design choices affect the quality of life for disabled people, engineers should be exposed to the role of disability in design at every level of education. The simplest and most equitable way to add the perspective of disabled people is by promoting their inclusion in STEM fields, requiring universities and other educational institutions to draft programs that attract those groups and then aid them in succeeding in a system not designed for them.

Disability is a great example of the need for interactive innovation as described by Arnold Pacey in his book *The Culture of Technology.* Designing towards greater accessibility forces engineers to broaden their thinking and implement more creative solutions. This is especially important for publicly-funded institutions, as the free market fails to support the development of devices with few users. As described in a British journal from 1973, machines addressing disabilities aren't attractive to companies: "If [a]machine was of use to a soldier the government would have paid for it ten times over long ago, but because it is only of use to a blind person there is no money. This is a typical attitude in this country and in America too. No manufacturer will do it until he gets an order for a hundred thousand, and the government won't give an order for a hundred thousand until you have got the price down" (Thring, 1973, p. 71). Engineers still have a moral responsibility to help disabled people, and to help them in interacting with society independently.

In this research, I will investigate the current state of disability in engineering education, both in terms of disabled people studying engineering and how student engineers incorporate consideration of disability into designs. I will then compare this to Pacey's matrix of interactive innovation, and then suggest improvements that can be made to existing education systems (Bejan, 2018, p. 42-47). In this paper, I argue that engineering not only can "transform even a serious disability into a minor nuisance" (Noë, 2015, n.p.), but that disability also leads students to recognize the social implications of their work.

Part I: The Limited Accessibility of Disability in Higher Education

The CDC defines many forms of disability, based on what capability is affected (CDC, 2018, n.p.): vision, movement, thinking, remembering, learning, communicating, hearing, mental health, and social relationships. The World Health Organization also defines three dimensions of disability:

1. Impairment in a person's body structure or function, or mental functioning; examples of impairments include loss of a limb, loss of vision, or memory loss.
2. Activity limitation, such as difficulty seeing, hearing, walking, or problem solving.
3. Participation restrictions in normal daily activities, such as working, engaging in social and recreational activities, and obtaining health care and preventive services.

While these different varieties of disability can require a wide range of solutions in engineering designs, this paper will mainly focus on the more obvious examples of disability: body impairment and activity limitation (struggle with the execution of a task).

Engineered devices to aid in everyday lives of disabled people have developed over the years. Adrian Bejan, a famous thermodynamic engineer and Duke University professor, goes so far as to say that "the old man in 2018 who is aided by hip implants, hearing aids, and trifocal glasses is more capable than the young man of 1518, whose body was ground down by physical labor and who struggled against disease" (Bejan, 2018, p. 47). However, there is always more work to be done, and engineers are vital in every stage of development. Engineers bring a necessary perspective, as they "can envisage what machines can be made to do, not only in terms of strength, rheological and other properties of engineering materials, but by ingenious mechanisms and by using the latest developments" (Thring, 1973, p. 57) in ways that many medical professions cannot.

Demographics of Disabled People in Engineering

As mentioned in the introduction, the best way to incorporate disability into engineering education is by having more disabled people in classrooms. Current data shows that disabled people, especially disabled women, are very underrepresented in engineering. The United States Department of Education estimated that students with disabilities were about 11% of undergraduates in postsecondary institutions, and that 4% of undergraduate students with disabilities were in engineering (Bellman, 2018, p. 655). Meanwhile, research shows that teachers struggle to facilitate inclusive STEM classrooms and would need additional training and skills to increase access for disabled students. (Griffiths, 2020, p. 294). Barriers cited by institutions on educating students with disabilities include limited staff resources to provide faculty and staff training on accessibility issues, costs associated with purchasing appropriate technology, and competing institutional priorities (Bellman, 2018, p. 646).

The absence of people with disabilities persists into the engineering workforce, suggesting that education systems in the past have also made it difficult for disabled people to study engineering professionally, and creates a lack of mentors for disabled students. With the growing prevalence of AI and increasing requirements of STEM education create barriers for disabled people who are unprepared or untrained. Looking at the overall trends from the U.S. Department of Labor, 15% of the U.S. workforce is in fields with computers, engineering, and science, and STEM fields comprise the top 30 jobs expected to grow quickest by 2026.

Employment outcomes for these disabled workers are drastically lower than those without disabilities, with as little as 21% of individuals with disabilities reporting gainful employment after graduation. With the increase in job opportunities in STEM fields, the labor market will hopefully create a greater demand for diversity of thought, experience, perspective, and backgrounds (Griffiths, 2020, pp. 293-295). However, people with disabilities currently experience less career success compared to nondisabled peers, and are less likely to finish their college education (Bellman, 2018, p. 646). Stronger integration of people with disabilities in the engineering industry must begin in schools, but companies should also more actively provide assistance to help disabled people find meaningful employment.

Women with disabilities are even less represented in the engineering workforce, being likened to “double jeopardy due to the related disadvantages that can impact transition outcomes in pursuing further education or careers.” Even disregarding disability, men occupy 76% of all STEM jobs, compared to the total job distribution across all fields being 53% men. (Griffiths, 2020, p. 294). There are a number of cultural factors that contribute to female discrimination, such as stereotype threat, implicit bias, and a lack of targeted professional supports. This leads to women with disabilities being employed at a low rate of 34.5%, compared to men with disabilities (41.9%) and men overall (85.6%) (Griffiths, 2020, p. 295).

Current Measures of Disability Inclusion

Some companies have made strides to specifically include workers with disabilities, such as the Center for Sensorimotor Neural Engineering (CSNE), which is one of many engineering research centers funded by the American National Science Foundation. As shown in Figure 1, their efforts have been successful in recruiting individuals with disabilities well above the average for engineering research centers. Specifically, they have a high rate of engineering leaders, although they essentially triple the average in every category. This case study proves that it is possible to increase the presence of disabled people without major hiring changes.

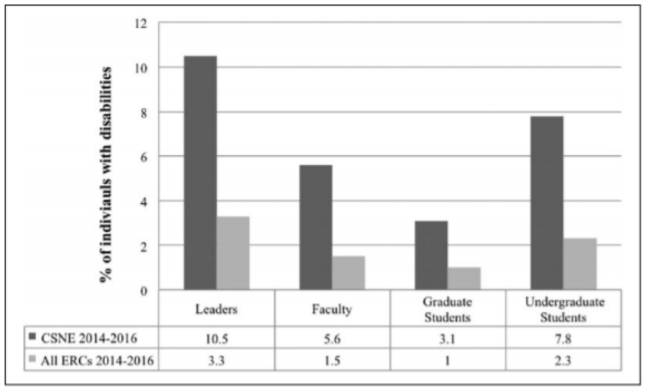

Figure 1: Workers with Disabilities by Role, in CSNE and all Engineering Research Centers (Bellman, 2018, p. 653)

There is legislation designed to prevent discrimination against disabled people, such as the Rehabilitation Act of 1973: “No otherwise qualified individual with a disability in the United States . . . shall, solely by reason of her or his disability, be excluded from the participation in, be denied the benefits of, or be subjected to discrimination under any program or activity receiving federal financial assistance or under any program or activity conducted by any executive agency” (Bellman, 2018, p. 646). The Americans with Disabilities Act covers similar requirements, and applies to both public and private schools. Most of the legislation addressing people with disabilities in education focuses on promoting physical classroom attendance, rather than full engagement in the classroom and lab activities (Marino, 2019, p. 361). Social cognitive theories suggest that more needs to be done to encourage immersive participation in class activities, an area where students with disabilities often encounter barriers. These theories recognize that "learning experiences shape self-efficacy beliefs and outcome expectations, which in turn, affect the formation of vocational interests, which subsequently influence occupational goals, choice actions, and performance attainments. (Menzemer, 2007, p. 1).

Part II: Applying Pacey's Interactive Innovation to Disability Case Studies

Pacey's "Innovative Dialogue" in *The Culture of Technology* provides a framework through which the importance of expanding the presence of disability in engineering education can be proven. In engineering universities as well as lower education, it is critical that "support is based on the needs of the individual, in the context of the subject matter, and occurs early and often in STEM education and professional settings" (Griffiths, 2020, p.299), all of which are key features of Pacey's arguments on interactive innovation.

It would be beneficial to first define interactive innovation, per Pacey's book. He describes the hallmarks of interactive innovation as "[bringing] together a wide range of ideas based on local needs… plus knowledge of locally available materials… and understanding of the imported… equipment". The opposite of interactive innovation would be linear innovation, which largely differentiates between advanced and primitive technologies, and describes technology developing along established paths, typically by large corporations (Pacey, 1983, p. 147).

Pacey's argument for interactive innovation claims that projects fail due to a "lack of any real understanding or dialogue between professionals and people" and the failure is blamed on the user's "lack of willingness to change." Pacey however identifies the problem as being that "the technologist… has never sat down with people to discover what their lives are about and what they want and need" (Pacey, 1983, p. 150). He suggests that linear views on innovation cause people to ignore the specific culture styles of technology use, preferring culturally neutral technology that dismisses specific community differences (Pacey, 1983, p. 147).

Pacey's Innovation Matrix

In order to assess various perspectives for a developing technology, Pacey provides a matrix, with questions to ask both the experts designing the innovation and the users local to the area. Pacey's matrix helps determine whether a particular solution is appropriate for the community at hand, and works well with his ideas of discipline of reversal: "deliberately attempting to understand a situation from a point of view opposite to one's normal stance" (Pacey, 1983, p. 152). The matrix asks the groups to answer the questions below in detail, then compares the answers:

Practical Benefits and Costs

What benefits are sought?

What costs, what risks, and what environmental impacts are perceived?

Who gains which benefits? Who loses?

Status and Political Advantage

What is the impact of the project in terms of status and prestige?

Who gains or loses status, power, or influence?

Basic Values

What is the cultural context?

What are the dominant values?

The three categories focus on different aspects of thinking that Pacey suggests are essential. Practical benefits and costs requires the expert to acknowledge his own very specific goals, compared to more general desires of the community. Status and political advantage remind the expert that not only could they gain status from a successful project, but also that the community could also gain prestige from it, like the city of Charlottesville does with the Rotunda. The final category reminds the expert to consider the values of the community such that new technology can integrate into their lives.

Case Studies of Technology for People with Disabilities

In this project, I investigated two case studies of assistive technology using Pacey's matrix to determine how successful engineers have been at creating disability technology, and how projects like this benefit engineering education. The first and shorter case is that of the Boston Elbow, a prosthetic device used to help those with above-elbow amputations. The Boston Elbow was the first artificial limb that used electronic brain signals to move, but this case focuses more on the diffusion of the technology. In this case, the application of the Boston Elbow is described as "not simply a match between professional diagnosis and technology at hand" and is mediated by "the influence of public policies, governmental institutions, and political processes." The distribution of the artificial limbs was limited by several factors: the compensation policies of federal and state governments, preference by veterans for prosthetics developed by the VA, and pressure from interest groups for cash benefits being the main compensation for physical disability (Percy, 1987, n.p.)

A more modern case is the development of Serious Games (SG), which are computer games designed specifically for educational purposes in Peru. The SG was directed towards children with learning disabilities, and incorporated a variety of games to appeal to specific learning disabilities. The first game was a match minigame, for children with Dyscalculia (difficulty with math and numbers), with children choosing balloons containing a calculation corresponding to a result. A shape minigame, for children with Dyspraxia (difficulty with planning and motor tasks), asks the user to match shapes on the screen. The last game is a missing character game for children with attention disorders and asks children to identify missing characters from a landscape. The serious games combine audiovisuals and immersive technology to improve memory and information retention. Skills developed through these games include hand-eye coordination, rapid reaction, and attention capacities, while encouraging critical thinking, relational aptitude, creativity, cooperation, tolerance to frustration, adaptability, risk-taking, problem-solving, and decision making (Avila-Pesantez, 2019, n.p.). Since the development of SGs are so new, there is little information available about their success in either the market or just for children with disabilities.

Part III: Benefits to Engineers and Engineering Education from Disability

Judging the two case studies above using Pacey's matrix, it becomes clear why the Boston Elbow failed and why SGs succeed, and how the lessons learned from designing towards disability are beneficial for all engineers. Starting with the Boston Elbow, it is clear that the experts were not aligned with users on the cost, prestige, and values behind the project. The creators of the artificial limb failed to consider how veterans wanted to pay for their assistive technology, as shown by the interest groups. The creator had good intentions, but it seems more likely that his primary motivation was gaining prestige by creating a novel product. Finally, he underestimated the loyalty that veterans held for each other, in that they would want a product developed by the office of veteran affairs.

With the SG case, the experts successfully engaged in interactive innovation in the design of their product by considering the specific needs and experiences of children users. By adapting the video game format, they appealed to the benefits sought by children (entertainment) and the product was easily replicable due to the digital format, potentially making it cheaper. While the creators do gain prestige from a successful result, there are also clear benefits given to children who can improve on their learning skills.

Positive Secondary Outcomes of Disability Engineering Research

The impact of projects to develop assistive technology goes far beyond the final product, however. Engineers from Ireland's National Rehabilitation Hospital engineering research laboratory expressed that "an important benefit of the majority of [the] projects has been the lasting impact on the student engineers who undertook them, giving them a better understanding of the humanitarian role of engineering" (Burke, 2010, p. 36). This would allow for these engineers to better align themselves with the goals established by Pacey's framework for innovative dialogue, giving attention to the needs of users and keeping in mind the context of their designs. The researchers in Ireland also noted that by trying to give increased independence to people with disabilities, students recognized that engineering can "have a positive impact on the lives of those who are disadvantaged or socially excluded [and gained] a sense of professional responsibility and compassion" (Burke, 2010, p. 36), establishing a clear sociotechnical benefit for any project developing assistive technology.

There are a number of other qualities that were nurtured through student projects to produce technology for overcoming the challenges of disability. Students were able to reflect on the role of engineers in increasing equity within their community. In student projects, ideas can be expanded upon in a way that is virtually impossible in commercial projects, occasionally leading to groundbreaking innovation, using the context of disability to design towards interactive innovation. Students can tackle real-world problems that, while worthwhile, would not necessarily result in financial success. These projects are also great ways to introduce interdisciplinary work to young engineers.

Social and Technical Skills Learned through Considering Disability

Another benefit that results from inclusive design is that student engineers learn how to include real-world limitations in their design process. Most engineering classes in undergraduate programs focus on limiting projects in very technical ways, such as factors of safety or the maximum forces a design is capable of withstanding. By designing around, for example, limited mobility of a limb, engineers would have to incorporate creative design alongside technical limitations.

Including engineers with disabilities in educational programs is vital to including disability into the program. People with disabilities are natural problem solvers because they must navigate a world that is not made for them. Thus they bring new perspectives to engineers, similarly to the way that Pacey describes information being shared between cultures as a result of interactive innovation. One way this can be seen is in the adaptations made to aid students with disabilities in learning machining skills, such as welding and machine cutting. The ADA and other legislation does require accommodations for people with disabilities, but functional access could be achievable for all users through better universal design. The main barriers for disabled engineers are “beliefs, perceptions, attitudes, and economic factors” of society, and changing the status quo of hands-on learning practices could change the image of being disabled at all, by giving every student the ability to have the same experiences as their peers. (Marino, 2019, p. 365)

It seems clear now from the research in this paper that, not only would increasing the accessibility of engineering to more people with disabilities help them find new opportunities, but it would also greatly benefit every one of their peers. Projects would have to be adjusted to be more inclusive, and increase awareness of the humanitarian context of engineering. Just as hands-on work in education increases physical skills, work on assistive technology increases the social skills of engineers, and creates more responsible and ethical engineers.

Conclusion

Inclusion of people with disabilities should be a major focus going forward for all engineering programs, as they are currently significantly underrepresented in American higher education, and face hiring difficulties in the workplace. Current assistive devices have made great strides in helping disabled people, but to continue improving them, engineers need to consider the perspective of disabled users in all stages of design. Not only does the increased acknowledgement of disabled users create better products, it also has a profound effect on student engineers, giving them insight into the social context of their field and aiding in establishing strong moral frameworks. The opportunities to develop assistive technology teach these students to design along Pacye's definition of interactive innovation, minding the perspective and needs of users alongside their own.

The results from this research show that increased diversity in engineering programs is not just a matter of equality, but also results in a benefit to the entire program. If universities were to take this research into account, they would be able to create more successful and ethical engineers, ready for the job market and to make decisions that take into account the needs of users. Unfortunately, it would take time to see results from implementing consideration of disability, and sometimes it may seem like the benefits are not visible at all. However, the research proves that, at the very least, there is no cost to the strength of the program by being more inclusive. Engineers with disabilities must be actively encouraged in order to build more responsible and creative engineering programs, and to meet the needs of an increasingly complex world. Engineering and disability have a two-way relationship: each has the opportunity to greatly improve the other, building a more equitable and opportunistic future.

References:

Avila-Pesantez, D., Delgadillo, R., & Rivera, L.A. (2019). Proposal of a Conceptual Model for Serious Games Design: A Case Study in Children With Learning Disabilities. *IEEE Access, Access, IEEE*, 7, 161017 - 161033.

Bejan, A. (2018). WITHOUT ENGINEERING, Civilization Does Not Exist. *Mechanical Engineering*, 140(5), 42 - 47.

Bellman, S., Burgstahler, S., & Chudler, E. H. (2018). Broadening Participation by Including More Individuals With Disabilities in STEM: Promising Practices From an Engineering Research Center. *American Behavioral Scientist*, 62(5), 645 - 656.

Burke, T., De Paor, A., & Coyle, E. (2010). Disability and Technology: Engineering a More Equitable Ireland. *IEEE Technology and Society Magazine, Technology and Society Magazine, IEEE, IEEE Technol. Soc. Mag*, 29(1), 35 - 41.

CDC. (2018). Disability and Health Overview. Centers for Disease Control and Prevention. https://www.cdc.gov/ncbddd/disabilityandhealth/disability.html

Griffiths, A. J., Nash, A. M., Maupin, Z., & Mathur, S. K. (2020). Her Voice: Engaging and Preparing Girls With Disabilities for Science, Technology, Engineering, and Math Careers. *International Electronic Journal of Elementary Education*, 12(3), 293 - 301.

Marino, D. J., Joseph, J., Williams, R., Jeannis, H., Goldberg, M., Grindle, G. G., ... Rivera, V. (2019). Accessible Machining for People Who Use Wheelchairs. *Work*, 62(2), 361 - 370.

Menzemer, C., Lam, P., Zhao, J., Zhe, J., & Doverspike, D. (2007). Enhancing Access and Fostering Science, Technology, Engineering and Math (STEM) Using Civil Engineering Materials Applications for Special Learning Disabilities Middle School Students. *2007 37th Annual Frontiers In Education Conference - Global Engineering: Knowledge Without Borders, Opportunities Without Passports, Frontiers In Education Conference - Global Engineering: Knowledge Without Borders, Opportunities Without Passports, 2007. FIE '07. 37th Annual*.

Noë, A. (2015). Physical disability and engineering of environments. *NPR.* https://www.npr.org/sections/13.7/2015/12/06/458454543/physical-disability-and-engineering-of-environments

Pacey, A. (1983). *The Culture of Technology: Innovative Dialogue.* MIT Press.

Percy, S. (1987). Engineering Disability: Public Policy and Compensatory Technology. By Sandra Tanenbaum (Philadelphia: Temple University Press, 1986. 167p. $24.95). *American Political Science Review, 81*(3), 1012-1012. doi:10.2307/1962718

Thring, M. W. (1973). Some Studies of Mechanical Aids for the Disabled. *Journal of the Royal Society of Arts*, 121(5198), 56.

Zaveri, M. (2018). Bike-share options are rarely available for people with disabilities. *NY Times.* https://www.nytimes.com/2018/12/10/us/bike-share-disabilities-detroit.html?searchResultPosition=25