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Engineering for Inclusion: Empowering Individuals with Physical and Neurological Differences through Engineering Invention, Research, and Development

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1. Background

The use of engineering tools, design, research, and thinking to create environments and capabilities whereby individuals who are currently under-employed or unemployed due to a physical disability (e.g., amputation or spinal cord injury) or neurological difference (e.g., autism) are enabled to become fully productive and employed members of society has been the implicit goal of decades of research at Vanderbilt University and elsewhere. At Vanderbilt University, progress in these areas has been greatly facilitated by the proximity of the School of Engineering to the world-class Vanderbilt University Medical Center and the resulting close collaboration between engineering and medical researchers. However, these approaches have typically been siloed into categories such as rehabilitation engineering (which focuses on the amelioration of physical injuries). We propose that these and similar activities—aimed at empowering individuals with physical challenges and neurological differences to contribute their abilities to the workforce specifically and to society more broadly—constitute a new subfield of engineering that we call Engineering for Inclusion, or more succinctly, Inclusion Engineering.

While Inclusion Engineering intentionally draws from many existing areas of Engineering, such as mechanical engineering, robotics, computer science, artificial intelligence, and systems engineering, Inclusion Engineering is distinct from several other approaches that might seem similar. For example, accessibility engineering and the closely allied field of universal design concern the use of technology and design principles to ensure the accessibility of facilities such as buildings, computers, and automobiles to the physically disabled and differently abled. In comparison, the goal of Inclusion Engineering is both more ambitious (since it aims at nothing less than the full engagement and utilization of individuals' different abilities, not merely providing them with access) and broader (since it addresses the neurological as well as the physical). Inclusive design is a design and architecture paradigm that emphasizes the necessity of understanding the diversity of users and seeks to include as many people as possible in the design architectural development process. Thus, it is quite distinct from Inclusion Engineering, although the practitioners of Inclusion Engineering often need to consider the diversity of the users of their technology as part of their research. In other words, inclusive design can be considered a component of Inclusion Engineering, but it is not equivalent.

The emergence of this new sub-discipline of Inclusion Engineering is perhaps reflective of the growing trend within society to embrace inclusion more generally. In particular, the positive impact of the idea that organizations, systems, and societies are improved when people of different abilities are fully included, with their needs supported and their differences celebrated, is increasingly supported by quantitative studies [1].

We note that the term "Inclusion Engineering" is also used in the steel industry to refer to approaches that optimize the role of nonmetallic inclusions in steel. We believe that the use of the term Inclusion Engineering, as we have defined it, can always be distinguished from the term's highly specialized use in the steel industry from context.

2. Examples of Inclusion Engineering

The invention, development, and deployment of engineered devices and environments that enable physically challenged and

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neurologically diverse individuals to lead full, productive lives from infancy to retirement is the goal of Inclusion Engineering.

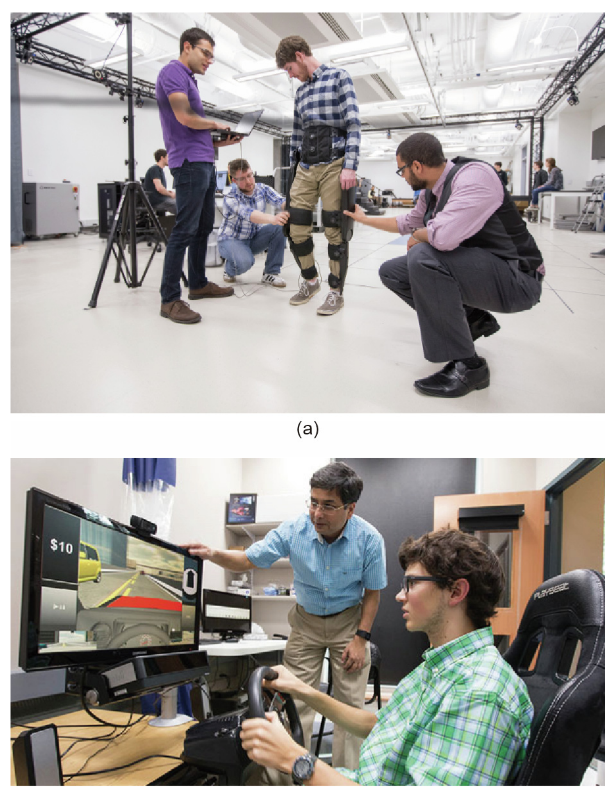
At Vanderbilt University, one of the major Inclusion Engineering efforts addresses physical disability. There are 47.5 million adults in the United States who live with a mobility or substantially limiting physical impairment, the costs of which account for 23.6% of all US healthcare expenditures for adults, amounting to 350 billion USD annually [2–4]. Such disabilities can result from spinal cord injuries or diseases such as amyotrophic lateral sclerosis (perhaps the most famous example being the late Stephen Hawking), Parkinson's disease, and multiple sclerosis. Reduced mobility leads to reduced physical activity, which leads to reduced fitness and other health problems, which then leads to further reduced mobility (e.g., Refs. [5–7]). This is a vicious yet highly consistent cycle that plays out every day in the lives of those affected and their families. As part of a broader effort to apply state-of-the-art robotics to resolve mobility impairment (including smart prostheses for amputees and wearable assistive robotics), the work of researchers from Vanderbilt University has been at the forefront of the development of intelligent powered exoskeletons for recovery (to be used immediately following injury with the goal of restoring physiological function so that an exoskeleton need not be worn permanently), movement assistance (to continuously assist individuals with chronic mobility impairments in activities of daily living), and fall prevention (to provide intermittent assistance only at critical moments to avoid serious injuries due to falls). Inventions at Vanderbilt University resulting in the Indego™ exoskeleton have been licensed to the engineering firm Parker Hannifin, which has spun off a division[†] to produce and market the device. The device has been approved by the US Food and Drug Administration (FDA). Vanderbilt University's exoskeleton research builds on more than a decade of research in robotics, intelligent systems, control, sensing, testing, and refinement (e.g., Refs. [8,9]) and independent evaluation (e.g., Ref. [10]). The future goals for this research (led by the Center for Rehabilitation Engineering and Assistive Technology) include increased naturalness in movement, lighter and more compact devices, and lower costs.

Another major Inclusion Engineering focus at Vanderbilt University is addressing the needs of individuals with neurological differences (e.g., those on the autism spectrum). Approximately 1/6 individuals has a neurodevelopmental disability [11], translating to over 50 million individuals in the United States alone; more specifically, 1/54 children in the United States are on the autism spectrum [12]. Neurologically diverse individuals often have difficulty mastering the kinds of everyday tasks that can be key to productive employment as adults (such as learning to drive a car or performing in workplace environments that require effective social communication). On the other hand, such individuals may have capabilities (such as responding to visual cues in a more insightful manner than neurologically typical individuals, e.g., Ref. [13]) that can form the basis of unique professions for the neurologically diverse, if only they can be supported in the communication of their insights [14]. At Vanderbilt University, extensive engineering research has focused on supporting neurodiverse individuals, such as a virtual-reality-based driving simulator designed to teach driving to autistic youth and adults [15], building and studying visual-imagery-based artificial intelligence systems to better understand how neuro-diverse visual thinkers process information and experience the world around them [14,16], and developing a computer-based, distributed, virtual space for multiple users to interact with one another and/or with virtual items to support flexible, safe, and peer-based social interactions that are difficult for children on the autism spectrum [17]. Much of the future research in this area will be performed under the umbrella of the newly established Frist Center for Autism and Innovation.

Aspects of Inclusion Engineering research at Vanderbilt University are illustrated in Fig. 1.

3. Impact

Perhaps the greatest impacts of Inclusion Engineering are the intangible benefits it can provide to individuals in terms of personal and financial independence. However, Inclusion Engineering can also provide society with considerable financial benefits by transforming cost into value. For example, of the 47.5 million adults in the United States living with a mobility or substantially limiting physical impairment at a healthcare cost estimated to be 350 billion USD annually [2–4], we estimate that only about 0.02% are currently assisted by exoskeletons. If research leads to lighter, more natural, more intelligent exoskeletons, and their adoption reaches 10%, savings of up to 35 billion USD could accrue. The average lifetime cost of supporting an individual on the autism spectrum has been found to be between 1.2 million and 2.4 million USD in the United States [18], with residential care or supportive living accommodation and individual productivity loss making up the highest costs; similar costs were found in the United Kingdom. Assuming that 1/54 of the 74 million children under the age of 17 in the United States (i.e., 1.37 million) is on the autism spectrum, their collective lifetime costs will be between 1.5 trillion and 3 trillion USD. If, thanks to Inclusion Engineering research, 10% of these individuals no longer require financial support, the savings would be in excess of 200 billion USD. Even



(a)

(b)

Fig. 1. Examples of Inclusion Engineering researchers at Vanderbilt University (photos courtesy of Vanderbilt University). (a) Researchers working on optimizing a lower body exoskeleton. (b) Driving simulator developed at Vanderbilt University to enable young adults on the autism spectrum to learn to drive. Monitors on the learning driver monitor physiological responses and attention to the road.

[†] http://www.indego.com/indego/en/home.

beyond reductions in support costs is the added value to society and the economy of the previously underutilized contributions to the workforce—cost is transformed into value. It is thus clear that the potential societal impact of Inclusion Engineering is enormous.

4. Summary

Inclusion Engineering is a new sub-discipline within engineering that refers to the intentional design of systems and structures to facilitate participation in work or social activity for individuals with different physical, emotional, or intellectual abilities. The key attributes of this new branch of engineering include both intentionality in all stages of development (from ideation to design, development, and production) and continuous learning to ascertain whether the adaptive function is fully meeting its purpose of inclusion. The core attribute is, of course, inclusion. This is important not only as a moral imperative for equity in the face of diversity, but economically. For students of the history and philosophy of science, Inclusion Engineering represents a paradigm shift. As Kuhn characterized it [19], philosophical breaks in tradition do not occur in isolation; they occur when context permits the reconsideration of explanation and constructive adaptation. Our context as we approach the third decade of the 21st century is one in which systematic exclusion on the basis of any form of difference, while never "right," is no longer tolerable. This new sub-discipline of engineering, then, breaks with tradition: It asserts that the design of products or the built environment without considering diversity is fundamentally incomplete. Further, it asserts that challenges posed to diversities of ability in the current environment require active consideration of adaptive tools to broadly enable successful participation in the economy and society.

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