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INVENTORS WITH DISABILITIES — AN OPPORTUNITY FOR INNOVATION, INCLUSION, AND ECONOMIC DEVELOPMENT

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In the United States, about 26% of the population reports having some form of disability. However, people with disabilities (PwD) are under-represented in science, technology, engineering, and mathematics (STEM). The representation of PwD as patented inventors is unknown, but likely under-represented, given their limited numbers in STEM and the workplace. This study set the goal of identifying PwD with patented technologies that have also been introduced into the marketplace. Using web searches and patent awards/applications, 21 influential inventors with disabilities were identified. The impact of these inventors was assessed and is briefly described. Technologies that were invented for PwD that have had mainstream success were also identified. Inventors with disabilities have made important contributions, but further study is required, as the inclusion of PwD in the inventor community is a nascent field of study that is important for expanding the innovation community.

Key words: People with disabilities; Patent; Invention; Innovation; Inclusion; Employment

INTRODUCTION

Inventors are frequently known to address challenges they encounter in their daily lives. For inventors with disabilities, solving these problems can have a life-changing impact not just for themselves but also for others who benefit from their ingenuity. According to the U.S. Centers for Disease Control and Prevention (CDC), more than 26% of the U.S. population, about 61 million Americans, are living with disabilities (1). The most prevalent disability type in the U.S. adult population is mobility disabilities (13.7%) (1), but the CDC also classifies disabilities relating to cognition (10.8%), independent living (6.8%), hearing (5.9%), vision (4.6%), and self-care (3.7%). Many inventions are created by people with disabilities (PwD) who have, through their inventions and the resulting products, regained freedom previously unavailable due to their disabilities, made others' lives easier, and, in some cases, have had a much broader impact.

The inventor's journey often begins with an education in the science, technology, engineering, and mathematics (STEM) fields coupled with exposure to innovative and creative concepts (2). Building on experience, interest, and aptitude, it is important to provide inventors with opportunities and to channel their creativity into invention, which may ultimately be translated into intellectual property and, if desired, commercial or societal success (3,4). The pathways along which inventors with disabilities develop and enhance their skills, harness their ingenuity and experiences, and capitalize on their successes and failures are fraught with pitfalls. There are many traps along the path to invention, and the process is rarely linear. However, nearly all paths start with the cultivation of interests and talent along with the development of

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skills in creation and invention (5). Generating most intellectual property (e.g., patent, trademark, copyright, or trade secret) requires acquiring specialized knowledge of the subject matter as well as a grasp of social or economic value (6,7). An interest and formal education in a STEM field are frequently needed (8).

Approximately 10% of employed scientists and engineers report having a disability (9). Understanding the issues and interventions found in a STEM laboratory environment from the perspective of students with disabilities (SwD), who have experience along the postsecondary educational pathway, could ultimately lead to higher STEM employment and more inventors with disabilities (10). Although a large portion (13.7%) of adults with disabilities have physical disabilities, students with physical disabilities remain a small portion (2.1%) of the undergraduate population (11). While both of these statistics could be under-represented due to some people not disclosing or identifying as having a disability, the discrepancy is staggering. This under-representation may be due to barriers SwD face in the postsecondary setting. The barriers and facilitators that SwD encounter are typically influenced by their physical and attitudinal environments, and the laboratory, fieldwork, and computing environments are no exception (12-15). A recent literature review suggests three broad categories in which barriers and facilitators to laboratory participation may be grouped: 1) the architectural built environment of the laboratory; 2) task execution in the laboratory space; and 3) the learning environment of the physical STEM laboratory (e.g., interaction with student peers and laboratory instructors) (16-18).

Therefore, the disparate access to and inclusiveness of STEM fields present challenges to invention and innovation for PwD (18). Many barriers are also faced by women and people of color, as they are also under-represented in the STEM fields (9). Moreover, PwD tend to have lower income levels, and a recent study showed that people from below-median incomes are nine times less likely to become inventors (19). Changes are needed, but there are some indicators on how to proceed. Despite the barriers faced, some PwD have become inventors who have contributed to the U.S. economy and/or have had a positive impact on society. This preliminary study attempted to identify historical and current U.S. inventors with disabilities and some of the contributions of their inventions.

METHODS

A preliminary study was conducted by searching the internet using various search engines (e.g., Google, Bing) for people who had disclosed their disabilities and who were identified as a scientist, engineer, designer, or inventor. The search terms used were inventor, designer, disability, disabilities, patent, invention, a scientist with a disability, and an engineer with a disability. We also searched for inventors with disabilities who were known to us and used the information on the web about them to help identify other inventors with disabilities. The U.S. Patent and Trademark Office's collectible card series includes inventors with disabilities, and they were included in the search (20). Once people were initially identified, a patent search was conducted to determine if the person had been awarded a U.S. patent as an inventor.

Moreover, for those individuals who had a disability and had a patent application or an awarded patent, a further search was conducted to determine if a product or process was brought to market derived from the intellectual property. If multiple inventors were identified on the patent(s), a search was conducted to determine if any of the co-inventors were reported to have a disability. The results were split into historical figures and contemporary figures. Historical figures were defined as deceased, whereas contemporary figures are still alive and, in several cases, still actively engaged in creation. The study focused on inventors within the United States who have had a published U.S. patent awarded or pending. The emphasis for inclusion in the results was on inventions that led to new fields of study, made significant advancements in their fields, or are widely used today.

We further conducted a preliminary exploratory assessment of the impact of cross-over technologies invented for PwD that became mainstream products or services. The search was not exhaustive but was intended to give an indication of the broader impact of inventions that may have been initiated to meet the needs of a particular subset of the population. Again, the focus was on products that started within the United States or that had U.S. intellectual property.

The Participatory Action Design and Engineering (PADE) model was examined as a tool to promote greater accessibility and inclusion of PwD in the invention and innovation environment.

RESULTS

Over 1,000 websites were examined to identify inventors with disabilities. Thirty inventors were identified; 21 are included here to highlight their contributions, and an additional five inventors are included in the "Discussion" section (not all of them had patents published or issued). Two of the inventors identified are authors of this study. PwD have made important contributions to American society and the economy. Some of the most famous inventors in the United States had disabilities, and others had a profound impact through their inventions while being lesser-known personalities. Inventors with disabilities have had an impact on products used widely by people with and without disabilities, while others have focused their efforts on products to improve the lives of PwD. The inventors represent several states within the United States, and the types of disabilities varied. The lives of the inventors highlighted are characterized by inspiring stories of determination, challenges overcome, and beating the odds. These inventors were leaders in their fields who understood the importance of developing the next generation of American innovators.

Examples of Historical Highly Impactful U.S. Inventors with Disabilities

The historical figures that were revealed and their inventions are described in this section.

Alexander Graham Bell *(learning disability – most likely dyslexia)* (1847-1922) lived and worked in Boston, Massachusetts, for most of his adult life. Although most well-known for inventing the telephone, he had many inventions and innovations in a variety of fields, and their derivatives are commonly in use today. He was also interested in heredity and genetics, which caused some controversy when he wrote a paper stating that deaf parents were more likely to have deaf children than non-deaf parents. Although he never advocated sterilization or legislation banning marriage for the deaf, his studies and comments are said to have assisted the eugenics movement at the time (21-23).

Ralph Braun *(muscular dystrophy)* (1940-2013) was born and raised in Indiana. Once his muscular dystrophy progressed to his needing to use a wheelchair for mobility, he created a powered scooter for himself and later retrofitted a jeep that he could drive his scooter into and then operate the jeep. The company he later started to adapt vehicles for wheelchair users remains one of the largest adaptive vehicle modification companies in the United States (24).

Thomas Alva Edison *(hearing impairment and potentially dyslexia and/or attention-deficit/hyperactivity disorder)* (1847-1931) is one of the most prolific and well-known inventors in history. He was born in Ohio and led laboratories in Florida and New Jersey. His impact on society is impossible to quantify, as the derivatives of his inventions, including the practical electric light bulb, are used in nearly every household and business every day (25).

Herbert Everest *(spinal injury)* (1885-1959) was a mining engineer who had a spinal injury after an accident in a mine in 1918. In the 1930s, he and a friend, Harry Jennings, started designing a lightweight and foldable wheelchair that would fit in an automobile, which was patented in 1936. They formed the company Everest and Jennings, which became the largest wheelchair manufacturer in the world through the mid to late 1900s (26,27).

Michael Graves *(spinal cord infection)* (1934-2015) was born in Indiana and was an architect and designer during his professional career. After a spinal cord infection in 2003, which led to paralysis, he focused on designing assistive technologies and home modifications for PwD. He is most known for his line of affordable designer products for the kitchen and home. He was appointed by President Barack Obama to serve on the Architectural and Transportation

Barriers Compliance Board (Access Board) (28,29).

Ralph Teetor *(partial blindness)* (1890-1982) was born in Indiana to a family with many manufacturing businesses. He later worked as an engineer for his family's automotive business and developed cruise control reportedly because of his chauffeur's erratic driving. Later generations of this technology are now used on virtually every vehicle and are what some have credited as paving the way for most autonomous vehicle features today (25,30).

Robert Weitbrecht *(hearing loss)* (1920-1983) was an engineer and physicist at various laboratories throughout the United States. He worked on many projects, including the Manhattan Project. While some references credit James C. Marsters (who was also deaf) as the inventor of the teletypewriter, the patent lists Weitbrecht as the inventor. The teletypewriter has led to modern text messaging and instant messaging technology (25,31).

Examples of Contemporary Highly Impactful U.S. Inventors with Disabilities

The contemporary inventors with disabilities identified in our search who have had a significant impact on the United States are listed below. The group is likely incomplete, but it is hoped that they are representative of transformative inventors with disabilities.

Chieko Asakawa *(visual impairment)* was born in Japan and became blind as a teenager. She has developed and continues to develop numerous technologies to assist people who are blind and visually impaired in using computers and accessing the internet. Her innovations in web accessibility, digital braille, and voice browsers are frequently used today. She currently works at IBM and is a professor at Carnegie Mellon University with research in the field of navigation for people with visual disabilities using artificial intelligence (25,32).

Peter Axelson *(spinal cord injury)* was born in Texas and sustained a spinal cord injury while training at the U.S. Air Force Academy. He is the founder of Beneficial Designs, Inc., and the inventor of the Arroyo Sit Ski. He has conducted research and development in various fields related to mobility, specifically with significant contributions to adaptive winter sports and accessibility of trails and sidewalks (33). He has many years of service on the Paralyzed Veterans of America Research Foundation board and is a leader in the development of technical standards.

Rory A. Cooper *(spinal cord injury)* was born in California. He was injured while serving in the U.S. Army. He has had the greatest impact on the ergonomics of mobility devices, prevention of secondary disabilities, assistive robotics, and adaptive sports. He currently leads a research center for the Department of Veterans Affairs (VA) and the University of Pittsburgh (34). Virtually every wheelchair on the market has been transformed by or is based upon some invention or innovation made by Cooper and his team, for example, the user interfaces algorithms for powered wheelchairs. He is an effective advocate for making STEM more accessible. He has launched several startup companies. Cooper has served on multiple federal advisory boards for the National Science Foundation, the VA, the National Institutes of Health, and the Department of Defense. Recently, his team has expanded their work into other inventions in the medical field as well (35-37).

Brad Duerstock *(spinal cord injury)* is from Indiana and is currently an associate professor of engineering practice and the director of the Institute of Accessible Science at Purdue University. His research focuses on integrating engineering strategies and technologies to improve the human condition and improve human-technology interactions (38,39). He has made significant contributions to making STEM more accessible for PwD.

Stacy Zoern Goad *(spinal muscle atrophy)* was born in Texas and received a law degree from the University of Texas and went on to practice patent law for several years. She founded Kenguru, Inc., to produce a fully electric car that people can drive from their wheelchairs (40,41).

Temple Grandin *(autism)* is originally from Massachusetts and is a professor of animal science at Colorado State University and is a frequent speaker and innovator in the fields of animal science equipment design, animal behavior, and animal welfare auditing (42).

Marilyn Hamilton *(spinal cord injury)* was born in California and was injured in a hang-gliding accident and used the principles and materials used in hang-gliders to revolutionize the manual wheelchair industry by introducing computer-aided design and manufacturing, greatly improving quality control and aesthetics (43). She is a founder of Quickie wheelchairs. She continues to be active in expanding her work to other rehabilitation devices.

Todd Hargroder *(spinal cord injury)* was born in Texas and has founded several companies focused on enhanced wheelchair components and other assistive technologies. His inventions include brakes, shower/tub transfer chairs, adjustable backrests, and power assist add-on devices (44,45). He was the founder and CEO of ADI, Inc., which was acquired by Stealth Products, LLC.

Hugh Herr *(lower leg amputation)* was born in Pennsylvania and is a professor at the Massachusetts Institute of Technology Media Lab. He was an expert rock climber who had his legs amputated as a consequence of severe frostbite. He has spent his career developing advanced and robotic orthotic and prosthetic devices (46,47). He has launched several startup companies.

Joseph Hidler *(spinal cord injury)* is an engineer who directed the Center for Applied Biomechanics and Rehabilitation Research at the National Rehabilitation Hospital. He has conducted research and published numerous papers on gait training and neural control of movement and motor learning. He is currently the CEO of Aretech, LLC, which makes devices for gait rehabilitation (48,49).

Jonathan Kuniholm *(forearm amputation)* was born in North Carolina and is a biomedical engineer and the founder and president of StumpWorx, LLC. He had his right arm amputated due to wounds received while serving in the Marines in Iraq. His career has focused on making upper limb prosthetics more comfortable and useful for various uses, such as exercise, writing, and picking a guitar (50). He was appointed to the National Council on Disability (51).

Jeff Minnebraker *(spinal cord injury)* was a recreational therapist at Ranchos Los Amigos rehabilitation center in Downey, California. He was an avid athlete and pilot and used his aircraft and engineering skills to create the first commercially successful aluminum, rigid, lightweight wheelchair — the Quadra Wheelchair. His impact was a catalyst for the lightweight and ultra-lightweight wheelchair revolution. Virtually every manual wheelchair on the market for full-time use today is derived from his groundbreaking work (52).

Lawrence T. Pileggi *(paralysis)* is originally from California and is currently Tanoto Professor and head of electrical and computer engineering at Carnegie Mellon University. His research includes numerous aspects of integrated circuitry design and methodologies and power systems simulation. He has started and sold several companies during his career (53,54).

S. Andrea Sundaram *(low vision, spinal cord injury)* was born in Michigan and has been visually impaired since childhood. He spent his early career working in research and development for a large consumer appliance manufacturer, where he invented several technologies used in home appliances. Following a spinal cord injury, he joined the Human Engineering Research Laboratories at the University of Pittsburgh to focus on developing assistive technology (55).

Crossover Inventions for PwD Turned Mainstream

PwD have long adapted mainstream technologies to solve their specific challenges, but there is also a history of inventions or adaptations originally intended to help PwD that have been adopted for more widespread use (56,57). In other cases, while the underlying technology may not have been developed with PwD in mind, early use of the invention in assistive technology applications provided evidence of its value and encouraged further development. Here, we present a few illustrative examples.

Typewriter: The first typewriter for which there

Table 1. Data on Influential Inventors with Disabilities

Inventor	Profession	Area/Domain of Invention	Number of Patents	Examples of Products Brought to Market	USPTO Trading Card
Historical Figures					
Alexander Graham Bell	Teacher for people with deafness	Transmitting sound, optical communications, hydrofoils, aeronautics	30	Telephone and metal detector	No
Ralph Braun	Quality control manager and then head of Braun Corporation	Mobility assistance devices	1	Battery-powered scooter, wheelchair lift for accessible vehicles	No
Thomas Alva Edison	Telegraph operator and later electrical science	Electric power generation, mass communication, sound recording, motion pictures	1093	Electric lightbulb, record player, cinematic camera	Yes
Herbert Everest	Mining, engineering	Lightweight foldable wheelchairs	16	X-frame folding wheelchair, folding commode chair, adjustable foot rests, Everest and Jennings	No
Michael Graves	Architect	Wheelchairs, hospital furnishings, housing modifications	>50	Tub rail, cane, wheelchair components	No
Ralph Teetor	Mechanical engineering	Automotive components	1	Early cruise control	No
Robert Weitbrecht	Astronomy and physics	Teletypewriter	1	Teletypewriter	No

Contemporary Figures					
Chieko Asakawa	Computer science, engineering	Technology for people who are blind or visually impaired	10	Intelligent text-to-speech processing	No
Peter Axelson*	Engineer	Assistive technology and adaptive skiing	9	Beneficial designs (FlexRim, Arroyo Sit Ski)	No
Rory A. Cooper*	Engineer	Assistive technology and robotics	>19	NaturalFit, Surge, Glide, Virtual Seating Coach, powered wheelchair joystick algorithms	Yes
Brad Duerstock	Neurobiology	Human-machine interfaces	5	Motorized wheelchair mount	No
Temple Grandin	Biology	Humane handling of livestock	1	Restraints for livestock	Yes
Stacy Zoern Goad	Lawyer/Inventor	Accessible transportation	1	Kenguru, Inc.	No
Marilyn Hamilton	Business	Assistive technology	2	Quickie Wheelchairs	No
Todd Hargroder	Innovation and business	Wheelchair components	7	Disc brakes, backrests, lateral supports	No
Hugh Herr	Mechanical engineer, biophysics	Prosthetics, orthotics, robotics	>50	Rheo Knee, BiOM T2, emPower	No
Joseph Hidler	Mechanical and biomedical engineer	Neural control of movement and motor learning	1	ZeroG Gait Trainer	No
Jonathan Kuniholm*	Engineer	Upper limb prosthetics	2	StumpWorx, LLC	No
Jeff Minnebraker	Recreation therapist	Ultra-light wheelchairs	10	Quadra Wheelchair	No
Lawrence T. Pileggi	Electrical and computer engineering	Circuits and power systems	> 40	Rapid Interconnect Circuits Evaluation (RICE)	No
S. Andrea Sundaram	Scientist/Engineer	Consumer appliances and assistive technology	25	Technologies found in dishwashers and washing machines	No

is evidence proving it worked was invented in the early 19th century by Pellegrino Turri to help his blind friend write letters (58). And, in 1870, the first commercially successful typewriter was patented by Rasmus Malling-Hansen, who wanted to create a means of communication for his students at the Danish Royal Institute of the Deaf-Mutes (59).

Word prediction: In 1988, Roy Feinson patented the first fully functional word prediction system to help deaf and hearing-impaired individuals communicate over the telephone without requiring specialized hardware at the sending end (60). The system used comparison rules to match the letters associated with each number on the telephone keypad with a dictionary of allowed words to display the most probable word on a screen at the receiving end of the call (61). Similar word prediction systems would later be incorporated into mobile phones to speed typing of Short Message Service (commonly known as SMS) text messages.

Audiobooks: Communication requires not only being able to express oneself but also the ability to access information. The first full-length voice recordings of books, known as talking books, were created in the 1930s for blind individuals and were made available for loan through a program operated under the United States Library of Congress (62). These were the precursors of today's audiobooks.

Text-to-speech and speech-to-text: Most of us may be accustomed to having our smartphones read incoming text messages while driving and being able to dictate a response, but text-to-speech and speech-to-text technologies are essential for some individuals to access computers. Both technologies have undergone rapid development since the 1950s (63). IBM, one of the early pioneers in speech-to-text, envisioned its main application as a dictation typewriter for office environments — eliminating the need for typists to transcribe Dictaphone recordings (63). When the first usable speech-to-text software came on the market in the late 1980s, people for whom the use of the keyboard was difficult or impossible were among the most enthusiastic early adopters, and the software developers took note (64). While the possible applications for text-to-speech were, and are, numerous, one of the first products to demonstrate the power of this technology was the Kurzweil Reading Machine. Introduced in 1976 and designed for visually impaired users, it could scan a document, digitize the text, and read it aloud (65). This device was one of the first implementations of optical character recognition compatible with a wide variety of fonts.

Eye-gaze control: Although eye-gaze tracking has been studied since the late 19th century, the first uses of it as a computer input device were in the 1980s for individuals with limited hand function (66). More recently, eye-gaze control has been used in consumer applications, such as camera focusing (67) and optimization of graphics rendering in virtual reality displays (68).

Segway transporter: In the early 1990s, Dean Kamen was inspired to create a wheelchair that could go upstairs and elevate to balance on two wheels so that the wheelchair user could communicate at eye level with someone who was standing or reach objects on high shelves (69). This product, the iBot, has enhanced the independence of many wheelchair users. The balancing technology developed for the iBot also made it to market as the far more well-known Segway Transporter — a two-wheeled platform that was controlled in part by the rider leaning forward or backward, with the platform moving to maintain the rider's upright posture (69).

Curb cuts: The first known curb cut was constructed in 1945 in the city of Kalamazoo, Michigan. Jack Fisher, a lawyer and World War II veteran who had a disability, began advocating for the project after hearing stories of injuries from some of his wheelchair- and crutch-using clients as they tried to navigate the high curbs in downtown Kalamazoo. Later, in the 1960s, a curb cut movement was initiated by Ed Roberts, a graduate student at the University of California, Berkeley, who had paralysis due to polio. Roberts and other students advocated for the installation of curb cuts to ease travel through the streets, and on September 28, 1971, the city of Berkeley adopted a policy to make streets and sidewalks accessible

(70). Not only do curb cuts make movement along the street easier and safer for users of wheelchairs, walkers, and crutches, but they also aid anyone using a delivery dolly, dragging a roller bag, or pushing a baby stroller.

Ergonomic kitchen tools: Kitchen tools as we know them today may have been entirely different if Sam Farber hadn't noticed that his wife was having trouble holding her vegetable peeler due to arthritis. Farber developed a wide, oval-shaped handle that was easier to use, regardless of the user's grip strength or the size or shape of their hand (71). Thus, the ergonomic kitchen utensil was born.

Ergonomic keyboards and mice: The World Wide Web launched in 1991, and the first commercially available ergonomic desktop keyboard was marketed only one year later (72). Shortly thereafter, in 1995, Kevin Conway patented a folding keyboard for laptops (73). Originally designed to aid workers with repetitive stress injuries from typing — such as carpal tunnel syndrome (74)— today, there are numerous designs of ergonomic keyboards and mice that make computer access possible for PwD and more comfortable for all (75,76). Studies have shown that ergonomic input devices not only reduce worker injuries but also increase productivity (75).

Closed captioning: The push for closed captioning was inspired by the work of Emerson Romero, a deaf actor and producer from the Silent Film era, who created subtitled versions of the new talking films being released in the late 1920s (77). In 1971, the first television show to include closed captioning was broadcast, but a special device was required to display the captions. Closed captions became commonplace on television shows throughout the 1970s and 1980s, and in 1996, the Telecommunications Act mandated that all TVs sold in the United States must include the capability of displaying closed captions. The ubiquity of closed captions across a variety of platforms has benefitted not only those who are deaf or hearing impaired but also anyone who wishes to view TV shows with the sound off. The evolution of technology, such as artificial intelligence, will continue to reduce the effort and expense of adding closed captions while continuing to improve their accuracy.

PADE as a Tool for Inclusion

To create a piece of innovative technology, we need to ask ourselves why we need to create such technology, who it involves, and what barriers may prevent it from coming to market. The PADE paradigm is an approach to the design, development, and assessment of technology with key stakeholders (e.g., engineers, designers, providers, manufacturers, scientists, and customers) working collaboratively in a transdisciplinary fashion (78,79) (Figure 1). In the engineering world, Participatory Action Design/ Research (PAD/ PAR) has been used since the 1940s (80). The method is similar to that of the NIH model of intervention

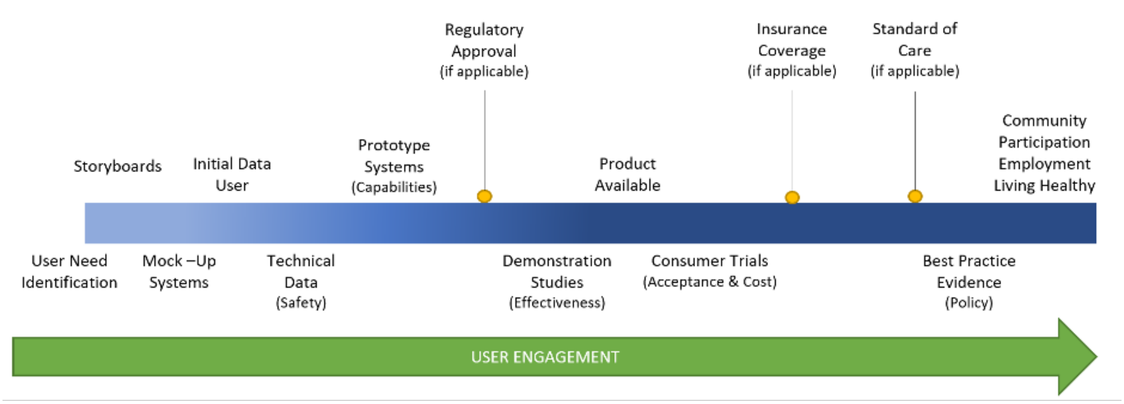

Figure 1. The Participatory Action Design and Engineering (PADE) model.

development in a clinical setting (81). However, the difference between these two models is that PADE acknowledges other barriers to the market, such as regulatory approval, policies, and potential coverage by third-party payers. These elements are important for the Assistive Technology (AT) sector, which is a relatively small market whose end-users may be reliant on health insurance or governmental services to supply such AT. These programs often have policies that stifle the innovation of future AT.

The most prominent element of PADE upholds user engagement throughout each stage, with a particular emphasis on the end-user. In the case of AT, these end-users are usually PwD with a range of impairments; involving them throughout user need identification and soliciting their feedback from early product testing will only strengthen the final usability evaluation (82,83).

It is important to recognize that PwD may qualify as members of other stakeholder groups, as they could be engineers, designers, scientists, clinicians, suppliers, manufacturers, policymakers, or other professionals and, in these capacities, can be valuable assets to the development process. Companies may, in fact, use PwD in the user engagement (customer discovery) process but have no incentive to disclose the process they used. Typically, PADE segments, such as end-user needs identification and the prototype-to-market process, are not documented in academic publications. As such information may lead to further refinement of the product in question or provide inspiration for other products, companies may regard it as an asset and therefore wish to keep it confidential.

DISCUSSION

Innovation is a keystone of the U.S. economic engine. Technological growth has become increasingly competitive and global; for countries to be competitive, support is needed for the innovation and invention community. Moreover, the innovation and invention community must be expanded to ensure that under-represented populations, such as PwD, have the resources and opportunities needed to be successful. With greater access to the invention ecosystem, PwD could be empowered with the tools and resources to improve their own standards of living and facilitate their integration into society. Beyond accessibility, equity, and inclusion, PwD could help to substantially increase the number of inventors. Both the economy and society could benefit by tapping into this underutilized population of creative people.

For PwD to become inventors, there must be greater access to STEM education and exposure to innovation and invention culture. Innovation and invention education must include transdisciplinary approaches, specifically disability community-based problem solving, PADE, embracement of learning from failure, collaborative team building, analytical reasoning, effective communication skills, and intellectual property awareness. Academic institutions, not-for-profit organizations, professional societies, and all levels of government must work together to create an effective learning and invention environment. We must learn, create, and infuse accessible and inclusive invention education in traditional STEM curricula and programming to improve the quality, scope, and impact of learning for PwD (84).

The inventors that we highlighted have had their inventions put into widespread use or have improved or have the potential to improve societal well-being, provide economic benefits to the United States, and/or have an advanced scientific understanding. There are some people worth noting that were revealed during our search but were not highlighted above, primarily because their inventions, while important, were derived from the groundbreaking inventions created by the inventors noted. For example, Doug Garvin (85), Alan Ludovici (86), and John Box (87) have been instrumental in advancing the design and manufacture of ultralight manual wheelchairs, with noteworthy patents brought to market and innovative businesses created (88). However, their work, while important, built upon the breakthrough innovations of Brad Parks, Marilyn Hamilton, and Rory Cooper. Sam Schmidt was a successful race car driver who, after a crash leading to spinal cord injuries, reengaged with auto racing, started a foundation, and began collaborating on inventions in various domains, mostly as trade secrets (89). Mike Schultz is a Paralympic and X-Games snowboard competitor and inventor who has developed innovative technologies for sports and recreation for people with lower limb amputations

(90). It is interesting that many of the contemporary inventors relate to one another, having consulted, collaborated, or contributed to leading efforts to expand opportunities together. Inventors with disabilities appear to have formed an informal network, which may be a result of their common barriers and their small numbers.

To our knowledge, this is the first study that attempts to identify and document the contributions of inventors with disabilities. It is difficult to identify inventors with disabilities, especially from public sources, as there is little data available. There are undoubtedly many inventors with disabilities who were not identified using our approach. However, it is not surprising that we found few inventors with disabilities, as people frequently do not declare their disabilities or identify as PwD. In addition, PwD are under-represented in STEM as are other populations. For example, women and people of color have been shown to be under-represented among inventors awarded U.S. patents (91,92).

FUTURE DIRECTIONS

There are several areas in need of further study. It would be beneficial to determine how to expand successful pathways for PwD to become inventors. This likely will include increasing opportunities to be successful in STEM education and related employment. Studies are needed to identify current inventors with disabilities to get a more complete picture. This could possibly include surveys of patent inventors to get a better understanding of the representation of inventors with disabilities within the community. There is a need for additional studies assessing the impact of inventions created by PwD across all categories of technology.

CONCLUSION

The inherent complexity of the invention and intellectual property ecosystem, with its multitude of contributors, interactions, challenges, and potential solutions, makes it difficult for PwD to succeed and for the pathways to change so that they are more accessible, equitable, and inclusive. There is no single solution for expanding the invention ecosystem to include more PwD. However, there are examples of people and technologies that have experienced some success, and there is a need for change. There must be a call for all organizations that are engaged with the invention and intellectual property ecosystem to support PwD in their journeys to effectively engage, learn, and realize the fruits of their creations while simultaneously benefitting society both socially and economically.

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