From College to Careers:

Fostering Inclusion of Persons with Disabilities in STEM

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About the Cover: A college student with a visual impairment participating in a summer research program at a Purdue research laboratory. Many disabilities are not immediately obvious or visible to others.

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Preface

From College to Careers: Fostering Inclusion of Persons with Disabilities in STEM is the product of a collaborative project initiated to examine current issues and explore future directions for improving the academic success and career entry rate of postsecondary students with disabilities (SWDs) in science, technology, engineering and mathematics (STEM) fields. This publication contains chapters prepared by four groups of invited authors who shared their pertinent research findings, expert knowledge and views on key topics pertinent to this topic.

Chapter 1, "Technologies to Facilitate the Active Participation and Independence of Persons with Disabilities in STEM from College to Careers," addresses strategies and assistive technologies to overcome the physical barriers that SWDs often face when pursuing STEM fields of study and careers. The authors describe a range of technologies for active engagement in practice-based activities that are essential for conducting research and performing required job tasks when assistance is not available. The chapter also stresses the importance of technology for supporting active learning of STEM-based concepts, laboratory procedures, and the use of scientific equipment.

Chapter 2, "Interventions with College Students to Increase the Representation of Persons with Disabilities in STEM Careers," examines academic problems, motivational and attitudinal factors, and skill deficiencies that have traditionally limited the representation SWDs in STEM fields. The authors review interventions that have been developed to enhance retention, persistence to graduation, and career readiness of SWDs in STEM majors and recommend approaches to improving the empirical basis for these programmatic supports.

Chapter 3, "College Students with Disabilities in STEM: Expanding Opportunities by Enhancing Communication of Evidence-Based Information with Stakeholders," focuses on strategies to enhance communication among stakeholder groups in order to improve the utilization of evidence-based technologies and methods that promote the success of college SWDs in STEM.

Finally, Chapter 4, "On the Sustainability of Programs for Students with Disabilities: Observations and Practical Ideas," explores the problem of sustaining programs and strategies that show promise for increasing the inclusion of SWDs in STEM disciplines. The authors describe an approach for devising strategies to establish and sustain successful programs based on examination of current trends of support for SWDs and other underrepresented groups in STEM education and evaluation of factors that influence this support.

The *From College to Careers* workshop, held on May 20–23, 2013 at Purdue University in West Lafayette, Indiana, brought together researchers, educators, program officers, and policymakers to provide feedback on the draft content these chapters during a series of panel discussions led by the authors. Workshop attendees were able to share additional research or program findings not addressed in the preliminary drafts, express their opinions on each panel topic, and make recommendations which were incorporated in the final versions.

It is our hope that the contributions of the chapter authors and inputs of the workshop participants that are published here will contribute to a better understanding of the problem of achieving greater inclusion of persons with disabilities in the national STEM enterprise, an appreciation of past efforts that have been made to address this problem in postsecondary educational environments, and a vision for future work that can lead to more effective solutions.

Bradley Duerstock and Clark Shingledecker
Editors

Executive Summary

The persistent underrepresentation of persons with disabilities (PWDs) in the science, technology, engineering, and mathematics (STEM) workforce must be addressed across the spectrum of K–12 and higher education. This publication focuses specifically on the challenges and potential solutions for broadening the participation of students with disabilities (SWDs) pursuing undergraduate and graduate STEM degrees and careers. Despite efforts to date, the underrepresentation of PWDs in STEM workforce* is an enduring problem that must be addressed with renewed emphasis on the comprehensive application of innovative evidence-based strategies at both the undergraduate and graduate levels. Some key findings and recommendations relevant to this problem are summarized below.

Assistive Technologies. Assistive technologies and accessible environments allow SWDs to perform typical scientific activities required for acquiring active learning experiences and to be more independent in graduate research and STEM careers. Although SWDs may be physically accommodated in STEM classrooms, practical learning occurs in biomedical laboratories, engineering workshops, during fieldwork, and even by flying aircraft. For SWDs to experience the same real-world and hands-on STEM learning opportunities that students without disabilities are typically afforded, efforts must be focused on curricular participation, not just institutional accessibility.

Programmatic Interventions. Programmatic interventions can assist SWDs in overcoming attitudinal, psychosocial, and educational barriers during STEM higher education. For example, first-year college transition support, summer research/work internships, and mentoring programs appear to positively impact SWDs success in STEM. However, short and long-term intervention outcome data has often been lacking or inconclusive. Appropriately scaled implementation programs and embedded research can help to build evidence-based models for broad application. In addition, data on interventions for SWDs in STEM can be augmented by results obtained with other underrepresented student populations that share many of the same obstacles to success.

Communication. A wide range of interdisciplinary data are pertinent to improving the inclusion of PWDs in STEM fields, making effective strategies to communicate evidence-based information to stakeholders—PWDs, educators, employers, and researchers—crucial to driving change. Different communication approaches are needed to uniquely inform and empower stakeholders to make positive changes toward increasing PWDs in STEM.

Sustainability. Achieving the full inclusion of PWDs in STEM disciplines is a complex task that requires a longitudinal approach incorporating the efforts of multiple institutions. Only through assuring the long-term viability of research and implementation programs can external pressure from stakeholder groups sustain and advance STEM inclusion efforts. Sustainability of successful initiatives requires constant innovation while maintaining essential core values. It is our hope that this publication will contribute to sustaining efforts to improve the representation of PWDs in STEM by providing a summary of progress to date and recommendations for future directions.

*NSF report on Women, Minorities, and Persons with Disabilities in Science and Engineering, http://www.nsf.gov/statistics/wmpd/2013/disability.cfm

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Technologies to Facilitate the Active Participation and Independence of Persons with Disabilities in STEM from College to Careers

CHAPTER
1

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Adapted scientific equipment, STEM-based assistive technologies, and universal design of environments are critically important to overcome the physical challenges that face many PWDs pursuing STEM careers.

PROBLEM STATEMENT

The molding of science, technology, engineering, and math (STEM) workers with disabilities occurs during higher education. However, STEM students with disabilities (SWDs) encounter many obstacles in obtaining a degree in practice-based STEM fields of study. Previous legislative efforts in higher education, such as the Rehabilitation Act of 1973 and the Americans with Disabilities Act (ADA) of 1990, have focused on preventing discrimination against SWDs and promoting reasonable accommodations in educational institutions. Though physical accessibility is essential, greater investment is needed to facilitate the active participation and independence of SWDs in STEM-based curricula as well as laboratory and field research activities.

Most practice-based STEM fields of study, including the life sciences, physical sciences, engineering, technology, and computer sciences, require substantial "hands-on" or practical training. The educational practice of "learning by doing" is rooted in their instruction (*1–3*). The National Science Education Standards advocated activity-based learning as a standard pedagogical approach for teaching science discipline to students at all educational levels (*4*). The ability of SWDs to actively explore and interact with scientific concepts and practices can improve their overall learning experiences as well as increase their independence and self-confidence (*5, 6*).

Therefore, the inability of SWDs to physically participate in practice-based STEM educational and laboratory research activities is particularly troublesome. The underrepresentation of SWDs in STEM disciplines have been attributed to a lack of interactive, independent learning experiences, diminished expectations, and limited opportunities for exposure to laboratory internships and other typical practical experiences often available to undergraduate science and engineering students (*7, 8*). Undergraduates with disabilities have stated that a key reason for not pursuing STEM fields of study was that they perceived the careers associated with these majors would require significant hands-on job activities inaccessible to them (*2, 9*).

Accessibility, Accommodation, and Assistive Technologies in STEM

Students with physical disabilities face physical and attitudinal barriers in higher education in STEM fields of study. The major physical barriers to STEM inclusion are both the science learning environments such as the laboratory classroom, research laboratory, and field (*10, 11*) and the scientific equipment and practices employed in STEM education and research (*2, 9*). Assistive technologies (AT) can assist SWDs in overcoming many of these physical barriers and, in turn, facilitate activity-based learning and inclusive participation by:

- Fostering their active participation in educational activities
- Improving practical laboratory task performance
- Promoting task independence during STEM coursework and research
- Granting greater interaction and engagement with classmates and teachers
- Providing greater understanding of scientific equipment and laboratory techniques, and their use

- Building self-confidence and ability to identify oneself as a student of science
- Mitigating the disparity of opportunities between SWDs and those without disabilities.

SWDs strongly rely on accommodations and accessibility to be successful in all postsecondary education majors. Eighty percent of public two- and four-year colleges and universities stated that they provide some special services for SWDs such as AT equipment laboratories, alternate exam formats and extended time, textbooks on tape, and notetakers and readers (*12*). However, 22% of SWDs who requested disability-related services reported not receiving what they needed (*13*). Thus, greater investment in educational tools for SWDs is necessary.

A lack of accessibility and AT for STEM education is not only an obstacle for SWDs but also for higher education instructors and researchers. Frequently, instructors do not know what accommodations and AT are available. There are limited resources that provide instructions or best practices for adapting research laboratory procedures and environments for SWDs (*14*). Greater information exchange is needed to share possible solutions for accommodating SWDs in STEM activities and providing AT training for educators, researchers, and other stakeholders (*1*).

This chapter provides an overview with examples of specialized STEM AT, practice-based educational programs, and AT design strategies for overcoming the physical barriers that SWDs encounter as they progress through STEM higher education and transition to a career in science and engineering. Special topics regarding specific accommodations for all persons with disabilities (PWDs) in STEM, whether students or workers, are also discussed.

PRACTICE-BASED TECHNOLOGIES AND PROGRAMS

Educational technologies comprise general use AT for reading, writing, and accessing teacher and educational materials, such as textbooks and lecture notes, as well as STEM-specific devices. STEM learning environments and programs have also been made accessible for students with different disabilities. This section discusses select STEM-based AT, techniques, or programs that have been demonstrated to be beneficial for SWDs and have the potential to significantly improve the independence of SWDs in performing typical educational tasks as well as permit them to actively participate in STEM coursework and research activities.

Access to Science Information

Print Materials for Blindness/Low Vision

In 1996, the United States Congress passed the Chafee amendment to the Copyright Act that allows government and not-for-profit organizations to produce alternate formatted text and other copyrighted material without requiring permission from the publisher (*15*), thus greatly expanding the availability of learning materials for students. Since then, a number of electronic textbook services have become available to provide texts to students with blindness or low vision (BLV). Electronic textbooks also benefit students with other types of disabilities, including mobility and learning impairments by creating a paperless format and permitting the use of text readers for aural learners. Providers include Bookshare.org, Learning Ally, American Printing House for the Blind (APH), among others (*15–17*). The Louis Braille book database, hosted by APH, is the most comprehensive database of Braille, audio, and large-print textbooks in the United States. These repositories provide a wealth of alternatively formatted, accessible content, including tens of thousands of different titles of K–12 and post-secondary education textbooks.

Accessing technical materials is one of the biggest challenges for BLV students to being fully integrated into STEM curricula. The alternate formats of choice are Braille, large print, electronic texts, and audio file formats

(*18*). Although these formats are becoming more widely available thanks to advances in access technologies, there are still many barriers to equal access to STEM-related content. As of now, there is no seamless way to translate mathematical and technical equations into the Nemeth Braille code for math and scientific notation (*19*). Further, there is no seamless way to produce raised line drawings that are properly labeled in Braille (*20*). These raised line drawings typically require significant effort by graphic designers and others to make functionally useful graphics for the blind. A need exists for a seamless way to produce dynamic raised line drawings that are properly labeled in both literary and Nemeth Braille.

Magnifiers and computer screen magnifications have proven to be highly effective solutions for the student with low vision (*3*). With new research in the areas of haptics and other full-screen refreshable Braille technologies, there is hope that innovations will occur in the coming years.

Automated Lecture Acquisition

Notetaking is one of the most requested school accommodations for SWDs (*12, 21*). Manual notetaking can be impossible or extremely tedious for SWDs, especially those with deafness, BLV, or upper extremity mobility impairments. Even for those with the fine motor skills to write, taking copious notes throughout a class period can be fatiguing. Acquiring lecture notes during class can also be challenging for students with learning disabilities and non-native English-speaking students, who may have difficulty understanding or interpreting instructors' oral lectures (*22–24*).

Extensive notetaking is particularly important in STEM courses, due to the density and rapid delivery of class information during lectures. Histology and biochemistry were selected in a student survey as the classes students would most appreciate having assistance with recording class information (*25*). In another survey of science and mathematics teachers in the U.S., 86% of students in high school biology classes took notes at least once a week (*26*). By the time students reached college, 99% stated that they take notes in science classes (*27*).

Notetakers or scribes are usually employed to acquire lecture notes for SWDs. However, SWDs have little control over the content of the notes being recorded by a notetaker. They are dependent on the skills and knowledge of the notetaker for the notes the SWD receives. In addition, notetakers may not be available during extracurricular activities, meetings, and private conversations (*21, 28*). Students who are deaf or hard-of-hearing frequently have trained captionists to transcribe lecturers' speech into text, using a keyboard abbreviation language incorporating phonetics, onto the student's laptop. Commercial systems, such as C-Print®, include the costs of the hardware as well as the services of professional captionists, which can range from $60 to $150 per hour. This is very expensive when considering the total number of lectures a student may have during a full school year (*29–31*). In addition, captioning is not always available outside of class or scheduled educational events.

Automated speech recognition (SR) technology has advanced tremendously over the past years, primarily for dictation or device control employing standalone software or web-based applications. SR is also being used to automate the taking of lecture notes either by providing near-instantaneous captioning of an instructor's oral lecture during class or post-lecture transcription of recorded lectures. Real-time captioning frees SWDs from having to take the bulk of lecture notes themselves and when notetakers are unavailable. Post-lecture transcription provides greater SR accuracy due to repeated processing as well as an opportunity to correct for errors. Lecture transcripts can be synchronized with the audio recording of the lecture as well as digital slides used in the class to produce comprehensive, multimedia class notes, which can be very useful for students with special needs (*32*).

Accessibility of Scientific Laboratory Instruments

Light Microscopy for Persons with Upper Limb Mobility Impairments or Low Vision

Students and scientists with physical limitations are hindered from performing many hands-on laboratory tasks by themselves. Light microscopy (LM) is one of the most ubiquitous and essential laboratory techniques performed by students in STEM courses, including biology, geology, medicine, botany, engineering, and food and materials sciences (*33, 34*). The ability to independently operate a light microscope provides students an active learning experience, which is necessary for enhanced recall of LM procedures and a more in-depth understanding of histological, microscopical, and other scientific concepts (*6, 35, 36*). Independent LM operation can also be crucial for conducting graduate research and pursuing a career in the laboratory sciences, such as medical technology, pathology, and biomedical research.

An automated microscope workstation, called AccessScope, was developed for persons with upper limb mobility and visual impairments to operate all features of a research-level light microscope including focusing, changing objectives, illumination settings, and exposure rates, translational movement of the stage, selecting brightfield or fluorescent imaging, and loading and changing slides without requiring human help. Only the initial loading of slides may require assistance (*37*). The AccessScope project, supported by the National Science Foundation (NSF), enables students and scientists with low vision (i.e., those with some vision, not completely blind) or quadriplegia due to a variety of conditions, such as spinal cord injury, cerebral palsy, rheumatoid arthritis, and stroke, to independently perform LM and related research tasks, such as image analysis, morphometry, or 3-D reconstructions of serial sections (*38*).

Due to increased automation of scientific instruments, it is becoming more possible to remotely control several different instruments for online access (*39*). AccessScope is able to be remotely controlled through the Internet by students or scientists with disabilities from home, other schools, or work. This allows for a single workstation to be shared by diffuse groups of users to decrease costs and provide a learning community. The advantage of remote operation is also evident for telemedicine applications, such as remote pathological observation of samples from other countries without needing to be physically present (*9*).

AccessScope has demonstrated that independent operation of microscopy was possible and useful for SWDs using a computer-microscope interface. A large video monitor allowed all users to view specimens better than peering through the eyepieces. Users with severe physical disabilities were able to, for the first time, independently perform this fundamental laboratory task (*2, 9*).

Chemistry AT for Students with BLV

There have been various development efforts to make access technologies available to students with BLV in the science laboratory classroom. The Skawinski group at New Jersey Institute of Technology developed the first text-to-speech interface with commercially available laboratory equipment (*40*). This laboratory setup was referred to as MacroLab. Although functionally useful, it was cost prohibitive, exceeding $50,000 per function for those outside the research group. Lunney and Morrison at Eastern Carolina University (*41*) and Wohlers at Truman State University (*42, 43*) successfully interfaced a commercially available electronic notetaking device known as a “Braille and Speak” in the early 1990’s. This solution was significantly more cost effective than the Skawinski solution which still was not widely used. A number of case studies regarding low-tech solutions to science content access have been published in science education literature. Tombaugh (*44*), Crosby (*45*), Smith (*46*), and Flair & Setzer (*47*) have documented adaptations to make tactile and Braille labeled periodic tables and other raised line

Purdue research intern with low vision micropipetting while performing a Western blot with the aid of task lighting from LED lamps.

graphical representations of scientific concepts available to students with BLV.

Further, the Independent Laboratory Access for the Blind (ILAB) project at Pennsylvania State University was established in 2004 through the NSF Research in Disabilities Education program (*7, 48*). Its primary goal was to develop a suite of talking and audible tools that could be used by students with BLV in the science laboratory classroom. These tools utilized the Vernier Software & Technology product line along with the Logger Pro scientific data collection software package. In addition, the Freedom Scientific® product known as JAWS™ was the only customizable text-to-speech (TTS) screen reader product on the market at that time. The JAWS scripting language allowed the ILAB team to contract with software engineers to customize JAWS to work with the Logger Pro software package. A partnership with Vernier Software & Technology was established by the ILAB team to decrease equipment costs. A series of best practices to incorporate ILAB tools into science published curricula were developed and commercialized through Independence Science, LLC (*49*). Independence Science develops new access technologies that can be used in the science laboratory classroom to increase equal access for students with BLV. Its primary mission is to increase hands-on student engagement by the students with BLV in the science laboratory in the hopes of inspiring this underrepresented population to consider career paths in STEM.

The Talking LabQuest (TLQ) device was developed by software engineers at Independence Science. This first of its kind portable handheld device speaks specific data points to students with BLV. Its small size minimizes the space required on the bench top and allows it to be used in the field, in informal learning environments. This almost pocket-sized scientific data collection device can be interfaced with more than 70 Vernier hardware probes. The TLQ can also be interfaced via USB to a PC to transfer data files and used in Logger Pro for higher functional analysis. This innovative access technology can also be used by students with learning disabilities to help focus attention on important aspects of laboratory activities.

Practical Learning Experiences

Practical learning experiences are essential for SWDs to acquire effective STEM training (*5, 6*). Unfortunately, due to inaccessibility of many science and engineering programs, the ability of SWDs to actively participate in science experimentation and research is typically very limited. Often, students with physical disabilities are relegated to literature review, software programming, and other passive research activities. However, disability does not have to confine SWDs to strictly sedentary tasks, but can involve practical educational activities, such as flight training, fieldwork in the geosciences, and participating in engineering design and development. Preparation is indispensable to teaching any practice-based subject with SWDs.

Flight Training for SWDs

Intentionally working to incorporate people with disabilities into undergraduate laboratory experiences in aviation is important both as an educational opportunity for the student, and as an opportunity to create a broader understanding of who has access to the aviation industry. Typically when discussing careers in aviation, it is very common to think immediately of professional pilots (*50*). Because of the stringent medical standards necessary to become an airline pilot, many people do not consider other types of employment within aviation (*51*). However, there is a vast range of other educational opportunities within aviation that may be suited for a PWD, based on their talents and skills. Aviation-specific career paths include air traffic controllers, maintenance technicians, federal airport/airline inspectors, and airport managers. Airlines and flight schools also employ professionals with many other non-aviation specific backgrounds: booking agents, classroom instructors, accountants, human resources professionals, dispatchers, planners/schedulers, and managers. Most of these career paths would require the same amount of minor accommodations to incorporate a PWD as any other industry, depending on the type of disability.

While there are many career choices within aviation open to PWDs, educational interventions that teach practical skills such as learning to fly can be an incredible confidence booster for any student (*52*). If the student has a valid driver's license (and has never been denied a flight medical certificate), they are eligible to receive a sport pilot's license (*53*). Students without a driver's license may still benefit from attempting flight instructions, but are not eligible for a license or for solo flight. Incorporating a SWD into an aircraft-based laboratory experience requires intentional planning before the student arrives, during the first weeks to make any readjustments necessary, and then periodically throughout the semester to ensure that everything is still running smoothly. This planning may not take a great deal of time, but needs to be done intentionally to ensure a positive experience.

Access to Geoscience Field-Based Learning Experiences

Geoscience has the lowest representation of people with disabilities (*54, 55*). Despite the fact that geoscience training and careers can be as varied and accessible as any other discipline, a

A wheelchair user in the Able Flight program learning to pilot an airplane.

lack of public awareness of the types of jobs associated with the geosciences may inadvertently discourage individuals with disabilities from exploring geoscience disciplines as a viable career option. This is likely due in part to a general perception that careers in the geosciences predominately require performing fieldwork.

The foundational understanding of geology has developed through the labors of field researchers who physically interact with the natural environment, traversing the terrain, collecting samples, taking measurements, drawing maps, and making personal observations of their surroundings (*56*). Traditional field-based experiences are often predicated on an assumed level of personal mobility and thus, may negatively impact learning experiences for students with mobility impairments if no recommendations for accommodations to field instruction are provided (*10*).

The first-hand observation and construction of field knowledge is associated with the concept of *embodied fieldwork* (*57*), and is especially important for a novice geology student with limited field knowledge and experience, regardless of their physical ability (*58*). The embodiment of the fieldwork experience is often represented by the effect that the field experience has on the student, both cognitively and physically. This embodiment is exhibited in the way the student begins to understand the content and operate as a field practitioner rather than just a student. This requires a physical interaction with the field environment as well as the learning experience. However, with the emphasis placed on field research in geoscience training programs, persons with various physical disabilities face profound barriers in completing field-based research requirements.

Although field research is vital in geoscience training programs, there are many subdisciplines within the geosciences that provide opportunities for students to become embodied in the science, without the necessity of physically conducting field research. In fact, performing geoscience today is anything but traditional. Specialized geoscience analysts can make observations and interpretations in order to understand different scientific phenomena based solely on data collected by others. The days of an individual researcher being involved throughout the entire process of data collection, analysis, and interpretation are quickly disappearing. Scientific discoveries are more often made by a team of scientists, rather than a single researcher in the field.

Once given the opportunity, students with physical disabilities are eager and capable of participating in scientific field exploration (*59*). In a study examining the construction of knowledge and understanding of specific geologic phenomena, students with mobility impairments traveled to Mammoth Cave National Park for an active learning field experience (*59*). Students obtained first-hand experience collecting geologic data through a cave-mapping exercise. This fully inclusive exercise enabled the students to use various geologic tools during their exploration of the cave site and implicitly demonstrate their physical ability to complete geologic field exercises at a site typically inaccessible to them. Due to students' mobility impairments and the lack of accessibility of the field site, extensive accommodations were necessary. However, pre-, post-, and delayed post-assessments of basic geologic concepts and cave knowledge indicated that these experiences produced overall gains in knowledge after participating in both the classroom instruction and field experience.

Technology must fill the gap to provide access to field-based learning experiences for students with physical disabilities. Examples of utilizing technology to obtain field experiences are increasing (*60*). Virtual Field Trips (VFTs) are being used to reinforce traditional field experiences, or simulate remote and inaccessible field sites, even extraterrestrial locations (*61*). VFTs offer multiple levels of interaction using technology including static images, panoramic scans, videos, and online tools such as Google Earth. Other methods of technological access to field-based learning are being explored using online video conferencing for individuals who are unable to get to the field site in person, enabling them to interact virtually in real-time with faculty members or student peers (*62*).

Another technological example of alternative instruction is through the use of simulation technologies, occurring in a collaborative project between researchers at Ohio State and Georgia State Universities. Based on the accessible field-based learning experience to Mammoth Cave National Park with students with mobility impairments (*59*), portions of the cave have been digitized through LIDAR scanning and have been transformed into an interactive simulation where SWDs can explore the cave and learn geologic content without traveling underground.

Organizing the push for enhanced access and inclusion in the geosciences is the International Association for Geoscience Diversity (IAGD). This international network of geoscience scholars and professionals is charged with identifying current research opportunities and instructional best practices for underrepresented SWDs, while seeking to raise awareness of improving access and exposure to the geoscience disciplines for students and geoscientists with disabilities (www.TheIAGD.org).

Accessibility of STEM Learning Environments

Most colleges and universities have accessible buildings, common spaces, and classrooms based on ADA guidelines. More progressive institutions have utilized universal design for learning concepts to make curricula and teaching methods more inclusive to all students, including SWDs (*63*). However, more can be done to make laboratory spaces and STEM equipment more accommodating. Laboratory infrastructure is all too often unwelcoming, even inaccessible, to persons with physical disabilities. It is a visually obstructive environment often navigated by narrow, blind paths, encumbered by high workbenches and overcrowded fragile equipment. This changing landscape requires the critical assessment of the physical accessibility of standard laboratory design. In order to support independence and foster inclusion, the first priority is to ensure an accommodating, safe laboratory environment with practical assistive solutions delivered in an accessible and ergonomic laboratory design.

Administrators, faculty, and researchers may be hesitant to allow SWDs access to expensive laboratory infrastructure. For instance, flight simulators, shop equipment, or biomedical science instruments require movement into, around, and out of confined areas. If their refusal to allow access stems from assumptions about safety or equipment damage, it is up to the student with a disability to understand and articulate their limitations and inform and educate the instructor if necessary. Emphasis on accessibility should be placed on allowing the student to participate to the maximum extent possible through consultation with supervising faculty members. This may require working with the school's disability resource office to convince faculty members of the importance of providing access. They may be able to suggest

A wheelchair user working in a wheelchair-accessible fume hood in a research laboratory.

workarounds or provide grant money to meet specific, pressing needs.

Accessible Engineering Laboratory

Creating accessible laboratory facilities is the first step toward establishing an academic environment where SWDs in the science and technology disciplines can maximize their academic potential. Laboratory space should be accessible to individuals with physical or cognitive disabilities. The Human Engineering Research Laboratories (HERL) at the University of Pittsburgh is the designated VA Center for Excellence for Wheelchairs and Associated Rehabilitation Engineering. Located in a state-of-the-art Leadership in Energy and Environment Design (LEED) certified building, HERL has over 25,000 ft^2 of accessible laboratory space fully accessible to people of all abilities. In designing HERL, many accessibility factors were considered. For example, the needs of power chair and scooter users dictated the hallway width, additional electrical outlets were installed to ensure that AT devices that use battery power can be charged as needed, the layout of individual workstations accommodates all standard wheelchairs, and additional space is available to students working with full-time caregivers. To accommodate individuals with visual and cognitive impairments, a directional floor pattern was used.

The 11,000 ft^2 prototyping facility at HERL

Figure 1. Wet Laboratory Work Triangle in ABIL with Automatic Adjustable-Height Lab Bench (**A**), Wheelchair-Accessible Lab Sink (**B**), and Wheelchair-Accessible Fume Hood (**C**).

provides equipment that allows students to support design, fabrication, and other technical aspects of rehabilitation and AT research projects. Each section of the shop (machine shop, welding shop, rapid prototyping, painting and finishing shop, stock storage and preparation, testing laboratory, electronics laboratory, and technical computing laboratory) is accessible to people of all abilities, and can accommodate most AT needs.

Accessible Biomedical Laboratory

The Accessible Biomedical Immersion Laboratory (ABIL) was developed from an existing biomedical or "wet" laboratory space at Purdue University and renovated according to the guidelines set forth by the ADA for building standards, those governing safety equipment installation prepared by the International Safety Equipment Association (ISEA) and approved by the American National Standards Institute (ANSI), literature review (*64, 65*), and perspectives of a quadriplegic scientist using a motorized wheelchair (*66*). ABIL was created to assess the accessibility, usability, or ergonomics of a typical wet laboratory and serve as a training facility and alternative research laboratory for SWDs to conduct scientific experiments if they cannot be performed at their current facility. Full descriptions of the construction of ABIL can be found at IAShub.org.

The adaptations to ABIL were based on the standard architectural features required to perform most biomedical or chemistry laboratory research experiments. The accessibility features of ABIL took into consideration traditional human factors principles established both for the home and workplace. For instance, ABIL incorporates a "work triangle" concept based on the kitchen work triangle developed by Dr. Lillian Gilbreth that included the sink, stove, and food preparation area (*67*).

ABIL's accessible "wet laboratory work triangle"—composed of the laboratory bench, sink, and fume hood—was designed to orient these commonly used work areas at close enough proximity to enhance efficiency yet provide enough clearance to promote comfort and ease of maneuverability. The accessible building standards and safety installation guidelines were only broadly prescriptive, focusing on heights from the floor, spray diameters, and general operability features. Therefore, testing done by a subject with a disability was necessary throughout the renovation process. However, usability can vary among individuals with disabilities. Even among wheelchair users, sitting height is typically higher when in a motorized wheelchair than in a manual wheelchair.

The first component of the accessible wet laboratory work triangle is the adjustable-height laboratory bench where most data collection and instrument usage is performed. A traditional stationary laboratory bench was replaced with a powered adjustable-height bench with a raised edge to protect users from spills. Through push-button operation, the height of this bench can be lowered to accommodate low stature or seated researchers or elevated for standing users (Fig. 1A).

The sink component of the laboratory work triangle was enhanced for multi-user accessibility by lowering the height of the counter to 34 inches from the floor and with a 29-inch knee clearance (Fig. 1B). The drain underneath the sink was also installed at the rear and padded with pipe insulation to accommodate wheelchair users' knees. These design considerations allow the user the ability to peer inside the sink. The orientation of the faucet neck and handles were placed in parallel to one another near the front corners of the sink for closer reach. The standard faucet handles have been replaced with larger paddle-style handles that are easier to manipulate.

The fume hood component of the laboratory work triangle is located to the right of the sink (Fig. 1C). The height of the work surface was lowered and wheelchair under-counter access area added. The customary cross-style valve handles were replaced with lever-style handles to enable ease of operation with limited hand grip. Fume hood switches were lowered near the counter within reach of wheelchair users.

Laboratory safety is a critical component of scientific research. Its accommodation for persons with physical disabilities cannot be overlooked. In ABIL, the emergency eyewash basin and showerhead were moved farther away from their supply line and support pipe to permit access to individuals in wheelchairs. The eyewash basin was also raised for adequate knee clearance and to bring the wash jets closer to the wheelchair user's face, thus eliminating the risk of loss of balance inherent when a wheelchair user leans too far forward. Two different length shower pulls were attached to the safety shower to enable proper reach from a standing or wheelchair sitting position (Fig. 2). A large wall sign over the safety equipment and enlarged directional signs on the floor were added to ensure this safety equipment could be easily located, even from the other side of the room.

Figure 2. Accessible Emergency Shower and Eyewash.

Accessible Aircraft

Before the student arrives at a flight facility, either the student or the instructor can initiate a conversation as to the nature of the disability and issues that may arise during training. Depending on the nature of the disability, there are a wide range of potential adaptions. A deaf or hard of hearing student may need to work with the instructor to ensure that easy communication is possible during flight training (*68*). Depending on the student's ability to read lips and the pervasiveness of the hearing loss, the use of hand gestures may range from essential to only for emergency situations, to ensure there is no confusion. Instructions written on note cards may also be used, but should be avoided during critical phases of flight as they may be dropped accidentally. If training is conducted at a non-towered airport, airspace that requires two-way communication can be avoided, but additional vigilance in monitoring for other traffic is necessary. Since updated weather information will not be able to be received by a person with hearing impairment, flights should be conducted in good, not marginal, weather. To operate at a towered airport, contact the tower in advance to inform them of the nature of the flight, the time of departure, and the approximate time of arrival for light-gun signals.

Adaptations for students with limited use of limbs will depend on their range of motion. Three issues will need to be discussed: how to get into and out of the aircraft, environmental factors that may make flying more difficult, and how to control the aircraft in flight. The method of getting into and out of the aircraft is best left to the student to determine, as they are most familiar with their individual abilities. Some students may need to schedule flying lessons at a particular time during the day, because they get tired or easily overheated in the hot afternoon sun. This needs to be discussed up front with the instructor, to avoid issues later during training. Students may be hesitant to voice their concerns, but it's much easier to make adjustments at the beginning, than to find out later the student isn't benefiting from the program.

In most aircraft, flying requires the use of (1) a yoke or steering wheel that controls both up-down motion and left-right banking, (2) a hand-held throttle that controls the power setting of the engine, and (3) rudder-pedals that yaw the aircraft left-right and brake. Use of simultaneous yoke and rudder pressure is necessary to ensure that turns are coordinated. Some newer light sport aircraft have been designed with the rudder pedals linked to the yoke, such that turning the yoke both banks and yaws the aircraft. Older aircraft can be modified by attaching a hand control to the rudder pedals, so that moving the hand control puts pressure on the rudder pedals. After putting one arm through the hand control, the pilot is able to move the rudder and brake pedals, while still keeping his or her hand on the throttle. Several companies make different types of hand controls that are approved for use in most common training aircraft. After obtaining an appropriate alternative control device for the aircraft, work with the local Flight Standard's District Office to ensure that the proper Supplemental Type Certificate and other paperwork are in order before beginning flight instruction.

DESIGN AND DEVELOPMENT OF AT FOR STUDENTS WITH DISABILITIES

Inappropriate design for the user is one of the most frequently cited reasons why up to 80% of AT are abandoned (*69*); design shortcomings have also been implicated in device failure and user injury (*70*). Resolving these design issues is essential to improving the independence and safety of AT users. AT has been noted as an important factor in determining PWDs' level of participation in society (*71*). Therefore, proper design is critical for PWDs to overcome barriers to full participation.

There are different means of developing AT devices for PWDs for use in STEM activities. AT development usually originates from the need to solve a problem encountered by an individual or group with a particular disability to perform a specific task. Therefore, AT designs may be initiated due to a particular need or situation that arises. In these situations, AT may be developed as a fee-based rehabilitation engineering service, during a class or service-oriented project to provide learning experiences for engineering or design students, or for a research project (*72–74*). These situation-based AT designs are often highly customized for a particular individual or type of disability and evaluated according to the ability of the end-user to perform a specific task. Situation-based AT designs might have limited applicability for other end-users.

In contrast, AT development that utilizes empathic design methods that confront barriers facing a defined group of disabilities or tasks, such as incorporating universal design, has wider application. The benefits of this empathic approach are that it is not customized for a specific purpose and can be broadly implemented. Additionally, AT development can proceed at any time and is not dependent upon waiting for a specific need to arise, greatly expediting the development process. However, a balance must usually be found between accommodating the individual with a disability and the disability group with the same condition or impairment. These two end-users may have different needs, which can make universal design difficult to achieve. Thus, a level of customization is always necessary in AT design.

Whether a situation-based or empathic AT design approach is adopted, it is imperative that the client or potential end-user with a disability needs to be part of the design process. Both approaches are discussed in the context of existing exemplar programs with emphasis on the learning benefits of AT design for developers, adequacy of AT solutions for PWDs, and recommendations for creating AT designs.

Situation-Based AT Design

Engineering design courses as a strategy to develop AT for PWDs

Design and project-based courses that engage students and faculty from both technical and health science disciplines enable the development of useful AT (*73*). In addition to developing tangible AT devices, augmenting such courses with a service learning component (e.g., working with a real client) enhances a student's academic experience, ensures the achievement of curricular goals, and teaches a student how to be a contributing member of his or her community (*75*). AT design classes allow students to experience real life scenarios, working with a person with a disability as an end user to create a technological solution that will allow them to live more independently (*76, 77*). Students learn technical skills as well as intangible skills like teamwork, responsibility, and enhanced interpersonal communication (*73, 78*). AT design and development educational activities may have profound effects on increasing the number of students that pursue STEM as well as helping to bring innovative AT to the market. Also, these courses may be an innovative way to focus on developing new AT that would allow SWDs to participate more fully in STEM activities.

Classes often combine instructors and students from multiple disciplines across the engineering and health sciences that result in better, more useful, and more reliable products (*73, 79*). Projects tend to be client-based but can range from an individual end user requiring an adaptive device to a non-profit organization wanting to build an accessible playground. These client-based projects promote university and community collaborations while benefiting individuals and institutions locally (*80*). Working with clients opens students' eyes to the inequities that exist for PWDs and the inadequate resources that are available to them (*76*). Additionally, by using PWDs as lead users in the design process, additional needs are considered. These "extraordinary users" not only have similar needs to able-bodied users, but also can communicate the latent needs of able-bodied users. For example, Hannukainen & Holtta-Otto (*81*) demonstrated this phenomenon in a case study where modifications were made to mobile phones that immediately benefitted PWDs but also included features that were helpful to the population at large.

Design Considerations for Client AT Solutions

King (*82*) describes the following components that need to be covered in the design text and other resources: device design from need recognition through marketing, team formation and management, specification, conceptualization, testing, prototyping, safety considerations, animal and human clinical trials, materials selection, optimization, manufacturing and quality control, economic issues, legal issues, ethics considerations, and government regulations. In addition to the process described above, AT design classes should follow a service provision model that includes (1) evaluation of client needs and skills for AT; (2) acquisition of AT; (3) selection, design, repair, and fabrication of AT systems; (4) coordination of services with other therapies; and (5) training of both individuals with disabilities and those working with them to use the technology effectively (*83*). On average, interdisciplinary teams produce higher quality results and value in terms of both the collaboration and the opportunities opened by working with people from another discipline (*73*). While many design classes focus on AT for specific individuals, there is an opportunity for students to create technologies that benefit a larger population and provide opportunities for technology transfer. For example, students may select to create a device or solution for a variety of individuals with physical limitations but still use one client as the model.

By considering a more universal design and flexible approach, their product can appeal to a wider group including those with degenerative conditions or an aging population, or for SWDs in STEM who may experience similar challenges in laboratories or other STEM activities due to inaccessibility. As suggested by May-Newman (*78*), assistive devices may also serve an able-bodied population by allowing them to complete tasks faster or more efficiently. Here lies an additional opportunity to instruct students on universal design (a strategy which aims to make environments and products as usable by everyone to the greatest extent possible without the need for individual adaptation) (*84*) and accessible design (satisfies specific legal mandates, guidelines, or ADA building codes with the intent of providing access for individuals with disabilities) (*85*). Both design strategies receive little attention in the undergraduate engineering curriculum (*86*). While eventual commercialization may not yield a substantial profit, the product focus of the development effort benefits both the students and the disabled community because students also learn from their involvement in the disclosure, patenting, licensing, and commercialization process (*78*).

Goldberg and Pearlman (*87*) suggest the following best practices for AT design courses: identifying a client through a reliable clinical partner; allowing for transparency between the instructors, the client, and the team(s); establishing multidisciplinary teams; using a process-oriented vs. solution-oriented product development model; using project management software to facilitate and archive communication and outputs; facilitating client interaction through frequent communication; seeking to develop professional role confidence to inspire students' commitment to engineering and, possibly rehabilitation fields; publishing student designs in repositories; incorporating both formal and informal education opportunities related to design; and encouraging students to submit their designs to entrepreneurship competitions.

Participatory Action Design (PAD) is a principle that involves stakeholders' participation in the entire product development process, including the complete feedback cycle of ideation, interaction design and ethical consideration, technology development and integration, prototype deployment and evaluation, and design refinement and iteration. SWDs are stakeholders in AT projects and share their perspective with nondisabled teammates, and their feedback is instrumental to the development of effective AT. However, involving SWDs in the PAD process provides benefits beyond project design.

Historically, PWDs have been excluded during the AT design process, even though they were the primary consumers. Involvement in design and fabrication of AT through PAD allows SWDs to assume competent roles where their personal experience with disability puts them at an advantage as they work alongside able-bodied students, thereby turning them into experts and leaders. As a means of educating aspiring STEM professionals, PAD empowers PWDs by turning them into indispensable

Figure 3. Initial Empathic Modeling.

contributors in the research and design process. At the same time, using PAD in education broadens understanding of disability and diversity by those without disabilities.

Empathic AT Design

Industrial design course as a strategy to bring PWDs into the design process

"Industrial design is the profession that determines the form of a manufactured product, shaping it to fit the people who use it and the industrial processes that produce it" (IDSA 2004). Industrial Design (ID) practitioners are innovative problem solvers, serving as the advocate and voice of the user in new product development. Typically, designers have been people without severe physical disabilities.

Design research provides a means of gaining insight into user needs; including their cultural, social, and aspirational needs, how to understand those needs, and how to integrate both into the design of good products. Design education is incorporating the role of the researcher into curricula to provide students with the skills necessary to ensure that outcomes reflect real user needs. Combining methods of research and evaluation (triangulation) can assist in understanding the problem and responding with design solutions (*88*).

Empathy is the critical component that deepens ID's understanding of users who may be very different from them. This dialogue allows the life-expert-user who engages with the world from an alternative perspective (i.e., PWDs) to become an integral part of the design process (*89*).

Disability + Relevant Design: Designing AT with PWDs

Since 2007, faculty in the School of Art+Design at the University of Illinois at Urbana-Champaign have collaborated with the Disability Resources and Educational Services to create an inclusive experience, integrating students with mobility and sensorial disabilities from other colleges and ID students into the same learning, research, and designing studio. The Disability + Relevant Design (D+RD) course enables students to develop more empathic approaches when designing for and with PWDs/life-expert-users. This is a paradigm shift from user-centered (i.e., IDs consult with the user to support effective product development) to a more intimate working relationship involving the user as a *co-creator*, actively imagining and developing concepts together with the designer in a human-centered approach.

"Relevant design" refers to product outcomes focusing on enhancing quality of life by improving the user experience in tangible ways (e.g., reduce/remove stigma, build in delight factors, use innovative materials). Some enabling products are designed to attract the least attention possible (*90*). Eyeglasses are an example of evolution in AT—once they carried stigma and today they can be seen as a fashion accessory, even worn without prescription lenses. Product appearance can create a visceral response from the user and can positively affect destigmatizing products.

The projects undertaken in D+RD emphasize development of simple, insightful AT products for activities of daily living (e.g., cooking, working, and exercising). SWDs actively create with the designers, using the ID's expertise, hands, tools, and skills when their own sensory and motor functions are compromised.

In D+RD, the design process begins with rapid immersion into empathic modeling exercises (Fig. 3). "The only way to experience an experience is to experience it" (*90*). The designer/SWD user teams jointly participate in product development. Brainstorming sessions, ethnography (e.g., observation, surveys, and interviews) and in-depth empathic modeling experiences assist them in narrowing the focus of their project. Mood boards help to visualize emotion, mood, or feelings evoked by experiences (*91*) and are used to explain how users feel *before* and *expect to feel* after the product is designed (Fig. 4). Mind maps help to establish the design direction (Fig. 5). The entire class evaluates ideation sketches and the most compelling products have initial models created, refined, and evaluated by the potential user/co-designer.

Immersed in a new learning environment with students from disciplines that are sometimes very different from their own—some STEM and some language based—they work collaboratively through cooperation, partnership, and teamwork which require mutual respect, tolerance, and patience (*92*). They develop a shared working language that helps to define and sometimes redefine terms, language, and processes. This takes time and effort to develop and nurture.

This opportunity to explore and research different experiences encourages students to stretch beyond their personal boundaries or capital to provide insight into user needs that exceed simple imagination. Prior to participating in this course, design students generally are not familiar with PWDs, and the participating SWDs, in turn, are unfamiliar with the design process. The lessons learned are less traditionally studio-oriented (drawing, model making) and more about developing and maturing the students' empathic horizons, becoming active partners as they learn to design together and satisfying increased user expectations of products (*93*).

The projects in this course create moments in student interaction that demonstrate a shift in thinking, practice, and designing. Students who have not experienced this approach tend to defer to their own universe (parents, siblings, roommates) for their research (*89*). ID faculty have observed that students who have experienced these specific approaches to designing for "the other" have incorporated these practices into their working design toolbox and continued to use these empathic strategies in their professional practice following graduation (*94, 95*). A secondary goal of this course is to open the ID profession to PWDs, not only for the development of AT, but also as mainstream product developers. Their user perspectives can often be uniquely different from industrial designers without disabilities.

SPECIAL CONSIDERATIONS FOR ACCESS TO STEM

Technology definitely has a role to play for increasing access to STEM, particularly for acquiring practice-based learning experiences. Though enabling activity-based learning is a crucial pedagogical approach to teaching STEM, other considerations can affect successful outcomes for SWDs interested in science. These considerations are discussed in more detail in the other chapters, however it is worth addressing how STEM AT accommodations are impacted by established and new educational practices and changes in the demographic of SWDs, including newly disabled veterans.

Classmates and Laboratory Assistants

During high school and college laboratory courses, SWDs are frequently paired with classmates without disabilities or provided a laboratory assistant to perform certain class activities. If a student with mobility impairments cannot manually operate a light microscope, the assistant will control the instrument while the SWD peers through the eyepieces or at the PC monitor if a digital camera is connected to the microscope. Laboratory assistants or classmates can also be a support for SWDs in STEM education by enabling SWDs to feel a sense of inclusion, develop meaningful social relationships with classmates, and gain self-confidence in their ability to be successful in STEM education and careers (*96–99*).

Though laboratory partners can help SWDs passively participate in practical coursework, SWDs are often unable to perform certain laboratory practical procedures by themselves. Not only are the learning benefits of active participation unattainable to SWDs, they cannot take practical laboratory exams by themselves. This is further complicated by the fact that SWDs are unable to access equipment or materials by themselves outside of normal class times. Therefore, preparing for practical laboratory coursework must be accomplished during class, when the laboratory assistant is available. In addition, graduate or professional students are expected to conduct research independently and are not always accommodated with laboratory assistants (*100*). Similarly, STEM workers with disabilities would be expected by employers to be able to work by themselves.

Figure 4. Mood Board.

Figure 5. Mind Map.

Simulations Versus Physical Practice

Advances in 3-D computer simulation technology has made it an efficient and affordable means of virtually training students and workers without needing to physically build the learning environment or resource. As an example, courses in introductory biology, histology, and pathology have transitioned from using student or teaching microscopes to microscopy slide simulations. Due to tremendous accessibility support of PCs for students SWDs, it is anticipated that microscopy simulations or “virtual microscopy” could accommodate a wide range of disabilities (*9*).

Microscopy simulations have been shown to be easy to use and more available outside of class times than using traditional microscopes. However, traditional microscopy offer students better image quality and more realistic user experiences, while being more technically reliable than virtual microscopy. Test scores using either method are statistically similar. In general, students prefer using traditional microscopes than microscope simulations, because classes using actual microscopes usually have greater teacher-student interaction and are better organized (*101, 102*). Thus, virtual microscopy offers an efficient method of displaying histology in laboratory courses. However, computer simulations should not replace successful didactic teaching practices (*103, 104*).

In a more practice-based curriculum,

medical students prefer to be trained using a combination of traditional and virtual microscope usage. Medical instructors also feel that actual microscope training is necessary for giving students essential microscope skills needed for advanced pathology, hematology, and microbiology classes, diagnostic medical testing, and independent research (*105*). Learning solely using simulations may result in an insufficient understanding of the nuances of light microscope principles and operation, and imaging concepts as well as how to prepare histological specimens on glass slides.

One AT solution, AccessScope, is an accessible light microscope that provides individuals with mobility or visual impairments the ability, many for the first time in their lives, to operate a research microscope without assistance. Accessible scientific instruments such as AccessScope grant accessibility as well as practical instrument training. Pilot studies tested the ability of SWDs to learn basic histology and microscopy concepts by comparing AccessScope usage to virtual microscopy. Subjects received higher test scores when first exposed to AccessScope during training than when initially trained using the microscope slide simulations. Therefore, the active process of using an actual microscope appears to provide tangible learning benefits (*9*). Both traditional microscopy and simulations are accessible options for SWDs and may be used in concert. It is conceivable that virtual microscopy will be used predominantly when teaching introductory STEM classes. However, accessible traditional microscopy (i.e., AccessScope) would be most useful when teaching practical STEM courses that stress microscopy usage, and during laboratory research (*106, 107*).

Three-dimensional simulations also have their place when introducing PWDs to new fields or environments that are not easily visited. A 3-D simulation of ABIL through the IAS Hub allows wheelchair users to virtually explore a typical wet laboratory space without having to worry about accessibility (Fig. 6). First-person users can run the 3-D simulation of ABIL as someone who is standing, using a wheelchair, or has a limited field of view. These different first-person perspectives allow others to understand the sight and movement limitations associated with these disabilities. For example, wheelchairs cannot move laterally and limited field of view requires individuals to visually scan large areas. In addition, 3-D simulations of common laboratory tasks allow SWDs to acquire a general understanding of the experimental methods and to devise possible accommodations before trying to physically perform the task (*108*).

Distance Learning in STEM

Online or "e-learning" has evolved immensely in the last decade. E-learning has been proposed as a means of accommodating SWDs without needing to physically attend STEM classes. Disadvantages of online learning are that there is no personal interaction with teachers outside of class or with other students. Likewise, online learning is not conducive to activity-based science learning through the use of laboratory equipment and experimentation (*109, 110*). These factors likely play a large part in the overall dissatisfaction with online courses by SWDs, even though their requests for accommodations during distance learning courses were being fulfilled (*111*).

It is unlikely that distance learning will have a wide-ranging impact on increasing the inclusion of SWDs in STEM fields of study that focus on acquiring and analyzing samples and reagents, such as biology, chemistry, and geology. However, there can be tangible educational benefits for SWDs in pursuing some types of STEM courses. For instance, vocational technology training usually requires access to unique and costly equipment and to a dedicated facility. Online programs, like those from Amatrol, use portable electrical instrumentation systems to walk students through measurement, tolerances, machine operation, troubleshooting, and maintenance. With appropriate computer access and adaptive aids, a student with virtually any impairment would be able to complete this self-paced training. This program simulates the interfaces and conditions found on actual mills, lathes, and additive manufacturing devices.

Actual machining and fabrication of products can be remotely performed using computer numerically controlled (CNC) machines or 3-D printers. The hands-on aspect of this work really occurs during the evaluation of the fabricated product. Other engineering or technology research can be conducted without needing to physically manipulate the instruments, including software programming, robotic control, and telemicroscopy (*9, 112*). However, assistance may be needed to initially load raw materials or samples, turn on the power source, and perform calibration. Programming, task performance, data collection, and analysis can be accomplished remotely.

Figure 6. **Three-dimensional simulation of ABIL showing the wheelchair-accessible sink, fume hood, and lab bench.**

Veterans with Disabilities in STEM

Veterans with disabilities (VWDs) represent a unique group of young adults returning to civilian life and facing new challenges for which they may not be prepared. As rehabilitation medicine has progressed together with the establishment of the modern industrial workforce, more research has been devoted to helping VWDs be productive citizens, with a strong investment from the military. During World War I, Frank and Lillian Gilbreth witnessed firsthand the tremendous effect of approximately 13 million injured soldiers from Europe and the United States with seemingly few options for gainful employment after discharge (*113*). They applied their motion studies research to devise modifications to common job tasks that would accommodate veterans with mobility or visual impairments. This concept of vocational rehabilitation has since been applied to all incoming VWDs and the disabled population as a whole (*113–115*).

As a result of the Operation Iraqi Freedom and Operation Enduring Freedom conflicts, the enrollment of veterans in colleges and universities has increased significantly in recent years. As more troops return home, the number of veterans pursuing higher education will continue to grow. Like other SWDs, student VWDs might not receive the level of support in the form of accommodations that would enable them to reach their academic potential. Unlike typical SWDs, veterans face unique challenges that often interfere with their academic experience. Lack of consistency across institutions about transfer of credit policies, complexity of the GI Bill, the new and unfamiliar college culture, and faculty and administrators' lack of knowledge about the military culture are just a few barriers that student veterans have to overcome as they enter academia. Yet, bureaucracy is not a major challenge compared to other difficulties many student veterans experience. Many veterans have newly acquired combat-related physical and cognitive disabilities such as traumatic brain injury and post-traumatic stress disorder, which interfere with learning. Fortunately, federal agencies and non-profit organizations have been supportive of institutions' efforts to create formal programs that aim to improve academic experience for veterans. Funded by the NSF, Experiential Learning for Veterans in Assistive Technology and Engineering (ELeVATE) at the University of Pittsburgh (PITT) has been successful in helping VWDs transition to undergraduate and graduate programs (www.qolt.pitt.edu/veterans/ELeVATE.php).

ELeVATE students work alongside their graduate student and faculty mentors on designing, prototyping, and testing AT devices. These students are also matched with informal mentors—former ELeVATE participants who have successfully transitioned to college. ELeVATE supports VWDs who are primed to transfer directly in to a bachelor's degree STEM program or through an "engineering technology" or similar associate's degree program designed to help veterans gain the necessary self-efficacy to succeed. VWDs may also benefit from gaining additional certifications that would provide them with additional career options (e.g., certified machinist) that would also help them build competency in key technical skills. This program also helps in transitioning from a community college settings to a four-year university by incrementally gaining academic (two years of coursework), life (self-advocacy), and technical (hands-on machining) skills.

In a similar format, the FATe (Fabrication and Assistive Technology in Engineering) program at PITT provides a comprehensive vocational training program for veterans. Over 12 weeks, FATe participants cycle through the fundamental areas of fabrication, including carpentry, welding, prototyping, and electronics to learn the basics of machining principles and practices. AT is used as a vehicle to encourage participants to contribute in a worthwhile endeavor. As participants progress through the program, they obtain an understanding of how these systems are designed and integrated. The final component has the FATe students independently design, develop, and evaluate their own product prototype using established design principles. After successful completion, participants will attain a Basics of Assistive Technology Fabrication Certificate from the University of Pittsburgh and be primed to take the National Institute for Metalworking Skills (NIMS) (www.nims-skills.org/web/nims/6) Machining Level 1 exam and for on-the-job training experiences in the manufacturing industry. The program's curriculum and activities include: orientation, goal setting, and career planning; workshops on disability support and exposure to areas of AT (mobility, communication, computer access, prosthetics, and orthotics, among others); computer-aided design concepts (SolidWorks, CAM software); rapid prototyping; tubing bending; and machining and milling. Partnerships with other STEM departments, small colleges, and industry provide an alternative, multistep track to ensure participants obtain proper training and employment upon completion.

Reasonable Accommodations

Section 504 of the Rehabilitation Act of 1973 and ADA guarantee the right for "reasonable accommodations" for SWDs to attain equal opportunities to succeed in education (www.ADA.gov, accessed August 2013). In the context of higher education, reasonable accommodations usually include special study areas, extended test-taking time, captioning and notetaking services, and educational assistive technology. Thus, it is easier to define what is not reasonable and assume that if the accommodation needed does not clearly fall under those guidelines, it is probably reasonable. There are three kinds of accommodations that are not considered reasonable: (1) if accommodations pose a direct threat to the health or safety of others, (2) if accommodations make a substantial change in an essential element of the curriculum (educational viewpoint) or a substantial alteration in the manner in which educational services are provided, and (3) if accommodations pose an undue financial or administrative burden (*116*).

CONCLUSIONS

This chapter focused on how critical AT and accessible programs can promote curricular participation and research independence in STEM fields. The American Association for the Advancement of Science (AAAS) has cited the importance of AT to assist students and scientists with disabilities in engaging in practice-based STEM learning activities and pursuing STEM careers. AT is rightfully described as helping "level the playing field in both education and professional employment" in STEM (*117*). The benefits of AT, however, is not limited to promoting equality, but also helps SWDs to identify themselves as fellow science students, scientists, or engineers. This ability to self-identify as STEM professionals, along with independence, builds self-confidence to pursue a STEM career.

In addition, innovative AT can significantly impact other facets of science and industry and vice versa. For instance, automation of scientific instruments through a computer or separate controller, often for high throughput operation, can also greatly benefit users with disabilities. A computer is one of the most adaptable technologies for PWDs and provides an accessible interface to many AT devices. The variety of input and output modalities for interacting with technology that PWDs are familiar with using (e.g., speech recognition, gesture recognition, single switch control) for effective or less fatiguing methods of operating equipment can prevent nondisabled users from repetitive stress injuries. Alternative user interfaces can also benefit how scientific information is perceived, such as through auditory changes, haptic feedback, or sensor measurements, instead of relying upon conventional assessment methods (e.g., color changes during chemical reactions, cell counting by visual inspection, listening for anticipated cues). The aforementioned detection methods are human-based, whereas alternative methods may be more unbiased and quantitative.
Also, different detection methods may yield unanticipated results and scientific discoveries.

RECOMMENDATIONS

Based on the cumulative findings from this work, the following recommendations for STEM AT acquisition, AT design and development for STEM, AT training, and AT standards and practices are offered to promote greater inclusion of PWDs in practice-based STEM professions.

STEM AT Acquisition

- STEM students and professionals with disabilities need greater access to STEM-based AT when beginning graduate school or a career so that they may be immediately productive. Vocational Rehabilitation service providers are typically inadequate at recommending such specialized research AT.

- Grant supplemental awards may assist SWDs pursuing STEM. The NSF Facilitation Awards for Scientists and Engineers with Disabilities (FASED) help SWDs acquire AT for funded research activities. The NIH Research Supplements to Promote Diversity in Health-Related Research helps fund SWDs on NIH awards. For both programs, SWDs must be in laboratories that currently have NSF or NIH grants and are required to conduct research directly related to the aims of the awards. It is unlikely that researchers would be motivated to recruit new SWDs to their labs due to these limitations.

AT Design and Development

- Improvements in the design and "look" of STEM-based AT can help in its destigmatization and widespread adoption by employers and workers with disabilities.
- STEM AT integration, functionality, and

acceptance will likely improve if the focus of AT design is on adapting the task to the user with a disability, rather than modifying the user to the task.

- STEM professionals with disabilities, particularly government employees and those with purchasing influence, should use their positions to advocate for scientific instrument companies to incorporate accessible design features in their products.
- Specialized STEM AT for SWDs can be developed through programs such as senior engineering design classes or service learning courses rather than through commercial or fee-based services. Initiatives, such as the NSF General and Age-Related Disabilities Engineering program that has funded engineering design courses that focus on developing innovative AT as a pedagogical tool, should be promoted.
- Robotics and other traditionally high throughput laboratory equipment used primarily for industrial applications can be adapted for use by students and scientists with disabilities to assist in performing laboratory tasks. PWDs can interact directly with robotic manipulators or mobile robots to perform a multitude of laboratory tasks without harmful effects (*118*).

AT Training for STEM

- Resources are needed to educate and train researchers and SWDs about possible accessibility accommodations and AT for STEM research. Information can be shared through the web (e.g., IAShub.org), instructional videos, workshops, and faculty and student presentations.
- A national lending library for STEM-based AT would allow SWDs to train and test potential devices without having to initially purchase this equipment. If a device is deemed useful, then slow-funding mechanisms, such as grants or Vocational Rehabilitation, can be used to purchase this equipment without delaying the ability of the student to conduct research using this loaned equipment.
- There needs to be commitment from the faculty and administrators of higher education institutions and research laboratories to actively recruit SWDs and strive toward facilitating full inclusion of SWDs in STEM laboratory courses and research rather than simply accommodating them on a case-by-case basis.
- Accessible physical laboratory environments, such as the Accessible Biomedical Immersions Laboratory (ABIL) at Purdue and the Human Engineering Research Laboratory (HERL) at PITT, can provide lab training sites for PWDs to practice using laboratory AT in performing typical laboratory techniques.

AT Standards and Practices

- Biomedical science and engineering classroom and research laboratories need to adopt basic architectural accessibility and safety guidelines for researchers with disabilities (*66*).
- To increase the inclusion of PWDs in aviation, (1) aviation educational and commercial facilities should be more accommodating, (2) aircraft manufacturers need to design more accessible aircraft, and (3) the Federal Aviation Administration must be flexible regarding medical standards to allow PWDs the opportunity to learn to fly and pursue aviation careers.
- Professional schools in medicine, veterinary medicine, dentistry, and other biomedical fields have technical standards for accreditation. Such standards frequently discourage or prohibit SWDs from pursuing the medical or clinical sciences. However, with AT accommodations, physicians and veterinarians with disabilities have been shown to still be able to effectively practice medicine.

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Interventions with College Students to Increase the Representation of Persons with Disabilities in STEM Careers

CHAPTER
2

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Ecologically valid research is needed to guide the development of interventions for college SWDs and to assess their impact on student retention, degree attainment, and STEM career entry.

OVERVIEW

This chapter reviews the use of programmatic interventions and practices aimed at increasing the success of persons with disabilities (PWDs) in Science, Technology, Engineering, and Mathematics (STEM) undergraduate degree programs, and in their subsequent passage into STEM career fields. We first outline some key academic problems, motivational and attitudinal factors, and skill deficiencies that limit the entry of PWD to STEM fields. We then examine direct interventions with students that have been employed at the college level to address these issues, and discuss available data on their application and impact. Finally, based on the authors' observations and those offered by experts attending a workshop on the improving the representation of PWDs in STEM careers, we lay out some elements of a path forward and recommendations for future intervention research and implementation efforts for college students with disabilities (SWDs) in STEM majors.

BARRIERS TO SUCCESS IN COLLEGE AND CAREER ENTRY FACED BY SWDs IN STEM

The broad goal of growing the participation of PWDs in the STEM workforce has been formally addressed using student programming across the full range of educational experiences starting as early as elementary school and extending through graduate training (*1–3*). One group that has received particular attention has been SWDs during the period spanning the transition from high school through graduation at the baccalaureate level and entry into the STEM workforce or graduate training. To emerge as successful scientists and engineers, these students must survive the critical transition to college and selection of a STEM field of study, persist through demanding academic coursework, develop and refine STEM-specific and personal skills, and make the second transition to competitive jobs or graduate programs. While this process can be daunting for many students without disability diagnoses, SWDs face particular obstacles and barriers that may be responsible for unrepresentative levels of recruitment to STEM majors, poor retention and graduation rates in those majors, and low rates of employment in STEM jobs and entry into graduate programs when they complete their degrees.

Several sources have documented the general obstacles encountered by SWDs as they approach and participate in postsecondary education (e.g., *4, 5*). Shingledecker (*6, 7*) noted that the specific barriers to the success of SWDs in STEM fields of study can be classified into five categories as shown in Figure 1.

Any college student's ability to enter and stay on a path toward a STEM career might be affected by the barriers shown in this figure. However, the possibility that these factors will limit the achievement of SWDs is of particular note because of the unique ways in which both visible and non-visible disabilities can adversely impact a student's educational history and personal experiences, habits, and attitudes. Some of these negative influences can be attributed directly to the effects of the disability itself. However, as discussed below, many are caused by prior experiences of these students in the home and at school that are affected by lingering misconceptions and erroneous beliefs held by STEM educational and employment gatekeepers, or even by the students themselves.

Interest and Motivation

While the outlook appears to be changing, college-level SWDs tend to have lower aspirations for STEM studies and careers than those without disability diagnoses. Enrollment data show that SWDs in college are more likely to choose degree tracks in the humanities than their counterparts without disabilities, and lag behind other students in most STEM majors, especially physical sciences and engineering (*8*). Inaccurate beliefs about personal potential and ability, lack of role models, limited hands-on experience with STEM, and insufficient knowledge of careers in science and engineering contribute to lower rates of electing STEM majors. Career interests and motivations are strongly shaped by academic and personal experiences during elementary and secondary education, and SWDs entering college may fail to consider STEM majors because of early failures in related coursework. Others may have been subtly steered away from these subjects by parents, teachers, and advisors because of their concern about providing special physical accommodations in STEM high school classes or their expectations about viable career choices for SWDs.

Additional motivational barriers to undergraduate success in STEM can appear after a student has started college. Students who “lose interest” in STEM, change majors, or leave college may do so because they have not been afforded experiences that build STEM identity. Carlone and Johnson (*9*) suggested that developing a science or STEM identity is crucial to academic success and pursuit of a career, and that students must have experiences that lead them to recognize themselves as scientists and engineers, and be recognized by others, including domain experts, as legitimate “science persons.”

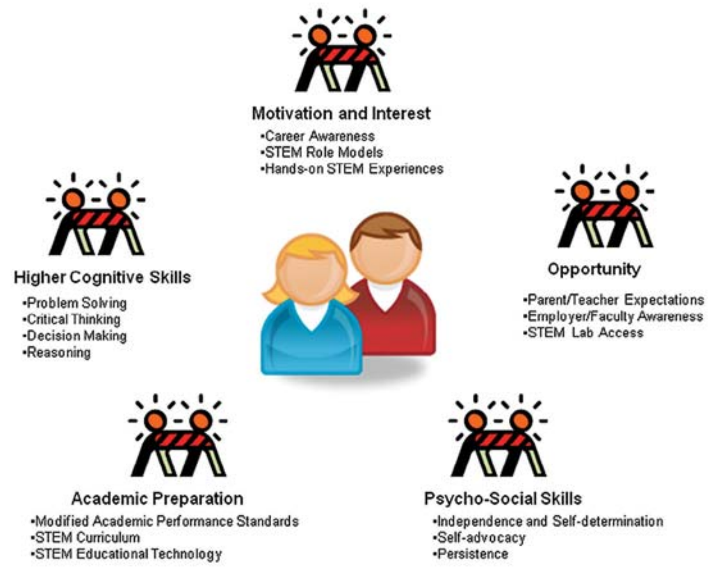

Figure 1. Barriers to Success in STEM Majors and Careers for Students with Disabilities.

Acquiring this identity—associated with persistence and academic success—requires the student to demonstrate competence in a range of legitimate science activities inside and (perhaps more importantly) outside of college classes in such things as undergraduate research opportunities and internships. Thus, the interest and motivation barrier is raised when SWDs fail to search for, find, or take advantage of opportunities to engage in these crucial activities.

Opportunity

SWDs also may have restricted opportunities to enter college, study, and excel in STEM fields and move to graduate school or jobs in STEM. In general, SWDs are less likely to enter any type of postsecondary education than those without disabilities. In fact, disabled students overall are less than half as likely as their peers to have attended college in the two years after high school (*10*). This is especially true for bachelor’s degree programs. Only 6% to 9% of youth with disabilities attend four-year colleges. Youth in the general population are more than four and one-half times as likely as youth with disabilities to be taking courses in four-year colleges.

Traditional, but persistent, factors affecting the opportunity to succeed in STEM studies include lack of physical access to laboratory and classroom spaces and the paucity of specialized laboratory equipment adapted for use by persons with sensory and motor disabilities. However, possibly more commonly experienced restrictions are created by a lack of knowledge and flawed attitudes and beliefs held by stakeholders in the student's education. These opportunity limitations may be externally or internally (self) imposed. Powerful internal limiters to opportunity are created by distorted beliefs of individual SWD about their own abilities and potential. Such beliefs, often created by past negative academic experiences and the lack of interaction with disabled role models in STEM professions of interest, can deter the SWD from even exploring education and careers in science or engineering fields.

External limits on opportunities can include parental attitudes about the value of college and fears of exposing their disabled children to the physical and emotional dangers of an unrestricted college environment; lack of instructor knowledge about disabilities, relevant law, and of methods for accommodation; and institutional failure of the college to include disability in their diversity commitments. One of the unique factors affecting opportunities for college SWDs is the STEM academic culture that drives beliefs about what tasks a student must be able to accomplish during training and the amount of assistance that can be provided. For example, requirements to demonstrate an ability to independently complete laboratory tasks requiring fine motor control can form a major barrier to success in the life and physical sciences for SWDs with limited upper limb function. These physical requirements are often rigidly enforced despite the fact that objective data typically do not exist to support their necessity for success in the field or to demonstrate that no form of substitute or assisted task is an acceptable alternative (see *11*).

Academic Preparation

SWDs often fail to receive adequate high school academic preparation in subjects key to STEM success at college. According to Horn and Bobbitt (*12*), when using criteria of high school grades in academic courses and college entrance test scores, SWDs in a nationally representative longitudinal study were much more likely to be only "minimally qualified" for college than their non-disabled counterparts. This deficit in academic credentials for college level work was confirmed in a more recent, smaller study that looked specifically at SWDs intending to enter four-year college programs (*13*). Detailed analyses of the level of rigor of the academic courses completed by the SWDs showed that the majority (76%) were ranked at the "core high school curriculum level or below" and that only 2% had taken coursework at a level of rigor that would fully prepare them for studies to obtain a baccalaureate degree.

Many factors are responsible for inadequate academic preparation. Specific learning disabilities and some neurological disorders clearly play a contributing role and may require early attention before and during high school to develop reading, mathematical, and executive control skills to make the student capable of success in college. However, problems also arise because high school course requirements and success criteria may be relaxed under the Individuals with Disabilities Education Act, and because parents and high school counselors sometimes fail to encourage capable SWDs to follow a rigorous college preparation course of study. In addition, intensive physical and/or academic support given to some SWDs in high school can results in poorly developed general study skills, note taking, and time management abilities that impair academic performance in the college environment.

Psychosocial Skills

In addition to academic skills and knowledge, there is a growing awareness that many SWDs face problems in college that are associated with what are commonly referred to as psychosocial, meta-cognitive, or life success skills. Adjusting to the relatively unrestricted environment of college can be a challenge to any student. However, many SWDs tend to face inordinate struggles with the transition process that interfere with retention and threaten their ability to achieve in demanding STEM majors. Getzel and Thoma (*14*) reviewed a number of the psychosocial skill deficiencies that are closely related to the concept of self-determination. Among the common problems displayed by new freshmen SWDs are underdeveloped skills for acting independently, problem solving, advocating for themselves with instructors and others, and communicating clearly and effectively. Low self-confidence, lack of persistence in difficult tasks following set-backs and failures, and ineffective time management strategies can be additional problems that directly impact academic success.

Some of these deficiencies are caused by the nature of a student's disability (e.g., autism spectrum disorder). However, they are also created by exposure to protective parenting as well as teaching and student support practices that limit the development and exercise of critical personal skills. As suggested by Wehmeyer (*15*), these restrictive social contexts detract from the critical levels of competence and autonomy that SWDs need to succeed in the unrestricted college environment and challenging requirements of STEM studies.

Higher-Level Cognitive Skills Needed for STEM

Because of the academic and psychosocial factors cited above, some SWDs arrive at college with poorly developed abstract thinking, reasoning, problem-solving, and critical-thinking skills that are essential to high academic achievement in STEM fields. Ideally, these skills are exercised and developed in high school science and mathematics coursework, and are central to modern curricula that employ inquiry-based methods. However, as noted in the supporting material for the Next Generation Science Standards (NGSS), research findings are showing that the traditional system of science education, which places more value on science as a knowledge base than as a way of thinking, is ineffective in teaching these fundamental skills (*16*). Modern curricula espoused by NGSS and earlier documents call for highly interactive hands-on, inquiry-based learning experiences Regrettably, such open-ended pedagogical methods calling for students to exercise advanced cognitive skills in ad hoc research activities are the most difficult to support using specific accommodations for SWDs (*11*). Thus, SWDs may arrive at the steps of college without the full benefits of these preparatory hands-on experiences, and may be limited in their ability to participate in them at the college level as well.

DIRECT INTERVENTIONS WITH COLLEGE STUDENTS

One factor that can vastly improve the likelihood that a college student will enter relevant majors and succeed in STEM is assistive and adaptive technology. As discussed in Chapter 1 of this volume, such technology includes both general educational support and STEM-specific devices. Two examples in the general category are equipment and software that make the printed page more accessible, enable writing, support auditory and visual comprehension, or make computing more accessible. STEM-focused technologies include accessible laboratory environments as well as devices that give students with specific sensory and motor impairments access to essential tools in various STEM fields. These include microscopes, test equipment, and virtual environments and representations that make activities and STEM training experiences accessible that would otherwise be unavailable to many SWDs.

A second and complementary approach used to address the barriers faced by college SWDs is the introduction of practices and interventions that are aimed at recruiting them to STEM majors, supporting their academic success in college and ensuring retention to graduation, enriching and enhancing their educational and STEM experiences, and preparing them for transition to work or advanced graduate training. This section describes the major types of interventions that have been used with college level SWDs to achieve these goals.

Two key points should be kept in mind as these general interventions are reviewed. First, in this chapter we concentrate on programmatic activities that directly impact the college student. While preparing the pre-college student for transition to college is an extremely important part of the solution, the focus of the study effort and workshop on which this volume is based was college-level SWDs and the efforts needed to increase their success while at university and in their preparation for transitioning to STEM careers. Thus, other than considering activities conducted immediately prior to, or during, college entry, we do not examine interventions for growing interest in STEM aimed at high-school or middle-school age SWDs, or for building readiness for transition to college. In addition, we do not consider efforts to benefit students indirectly through interventions focused on other stakeholders in the process of STEM inclusion. These include faculty interventions such as training in disability awareness and in making classroom materials and processes accessible. Other important, but indirect interventions not discussed here are those designed to shape institutional policy and culture to the benefit of SWDs including efforts to incorporate disability as a part of the diversity commitment of the university and to adopt Universal Design for Learning concepts in course design and teaching that can lead to inclusion of students with specific disabilities and improve education for students as a whole.

The second issue to be noted in reviewing this list of interventions is that specific methods of delivering the content or treatments included in some interventions can differ greatly. For example, mentoring activities can be accomplished with traditional in-person and group contact, telephonic interactions, and a wide variety of electronic communication methods ranging from e-mail to shared experiences and activities situated in a virtual environment. To the extent possible, in the following list we do not distinguish between the same types intervention accomplished using alternative methods. However, the ultimate importance of delivery mode in determining the effectiveness of interventions in terms of impact on student outcomes or on controlling the cost of implementation is a factor considered in a later section of this chapter.

First-Year College Transition Programs

College orientation programs, first-year experience seminars, and freshman learning communities are examples of a well-established movement in U.S. colleges and universities to improve the success of new students who are making the transition to postsecondary education. Ample evidence confirms that these courses can improve academic performance and increase critical second-year retention rates for many students, especially those who enter college with nontraditional preparation or marginal academic performance in high school (*17*). First-year seminars typically aim to facilitate academic and social acculturation, increase student engagement, and build core independent study, note-taking, and time-management skills. In a common variation of these courses, themes and topics are added to the syllabus to address the interests and needs of students who are members of racial and ethnic minority groups, participants in athletic or academic honors programs, or studying in specific academic majors (*18*).

In their investigation of factors affecting first- to second-year persistence, Mamiseishvili and Koch (*19*) confirmed that the widely held theory connecting academic and social integration to retention is applicable to SWDs. As noted above, this broad integration is a central objective of most first-year seminar courses. Thus, it is somewhat surprising that, although many SWDs share common risk factors for college success including underdeveloped self-advocacy skills and a need to make broad personal and lifestyle changes to accommodate the increased independence of college life under the Americans with Disabilities Act (ADA), few first year experience courses seem to have been specifically tailored to address these students. This appears to be especially true for SWDs pursuing specialized majors, including those in the STEM fields. One example of a course designed specifically for new SWDs in STEM majors is the credited First Year Learning Community course offered to participants in the National Science Foundation (NSF)-sponsored Ohio's STEM Ability Alliance at Wright State University.

Academic Support

As discussed earlier in this chapter, insufficient academic preparation forms one of the primary barriers to STEM postsecondary education for SWDs. Thus, providing academic support for SWDs can be a major factor in determining their success in demanding STEM classes. When dictated by the nature of the student's disability, academic support in the form of tutoring, assistance with adaptive technology selection, and training to improve reading, writing, and note-taking performance may be offered as a part of ADA-mandated accommodations provided by an institution's disability services office. Some colleges and universities also offer free academic support services for all students taking entry-level coursework. However, for SWDs in STEM fields, additional help can be needed to promote their success in advanced coursework, especially in the area of mathematics and related disciplines that employ complex computational methods and concepts. In these situations, SWDs may face particular difficulties in locating tutors with the appropriate qualifications and paying for their services. Formal assistance in finding and funding tutors has been one part of

Greater diversity in science requires people from different backgrounds, including those with disabilities.

some NSF programs aimed at increasing STEM participation of PWDs, for example, Ohio's STEM Ability Alliance (OSAA).

Mentoring

As evidenced by the proliferation of programs, mentoring has become a national priority for supporting college student success (*20*). However, as noted by Crisp and Cruz (*21*), it appears that mentoring research has made little progress in identifying and implementing a consistent definition and conceptualization of what constitutes effective mentoring. Mentoring was broadly defined by Roberts (*22*) as "a formalized process whereby a more knowledgeable and experienced person actuates a supportive role of overseeing and encouraging reflection and learning within a less experienced and knowledgeable person, so as to facilitate that persons' career and personal development." STEM mentoring (*23*) is a specific subcategory of this type of activity which shares the features of mentoring in other academic areas including psychological support and support for setting goals and choosing a career as well as academic subject support.

STEM mentoring activities aimed at college-level SWDs are often categorized as "professional" or "peer" mentoring (*24*). In professional mentoring, students are matched with mentors who have success, knowledge, and experience in specific fields of expertise. In the case of STEM, this may include faculty researchers or teachers, scientists employed in the public or private sector, or advanced students completing graduate or post-graduate work. Peer mentoring seeks to match students with mentors who share important characteristics with the students. These shared qualities may include similar STEM fields of study where the mentor can convey knowledge and proven success strategies, similar disability concerns, or both. Peer mentoring by advanced SWDs in STEM majors is used by OSAA as part of a comprehensive set of interventions to bolster first-year retention.

Mentoring often includes the use of learning and training practices that include components of Universal Design for Learning (UDL), in-person, online and social media tools to promote connections and community, and information resources that provide continued support of STEM ambitions. The Georgia STEM Accessibility Alliance (GSAA) (*25*) is one of a number of NSF funded programs that offers college SWDs access to mentoring. GSAA emphasizes online mentoring and related internet-based virtual learning experiences to improve persistence in STEM majors and entry rates to graduate school.

Exposure to STEM Role Models

As activities that may sometimes be considered distinct from mentoring, interventions aimed at providing experiences for SWDs with professional role models are considered desirable as components of programs to build and sustain student interest and motivation toward achievement in STEM and entry into professional careers (*26*). According to social learning theory (*27*), modeling the behavior and attitudes of others is a primary learning mechanism. Effective role models are individuals that the modeler perceives as having authority, knowledge, and power in the endeavors to be emulated. In addition, students are most likely to emulate desired behaviors when they are able to draw similarities between themselves and the role model (e.g., gender, race, or background). This is an especially important factor for SWDs in STEM because many of them are unlikely to have casual encounters with professionals or even advanced students with similar disabilities in a STEM career domain where only 1% of those holding terminal degrees have disabilities (*28*).

STEM role models can defined as historic or living individuals with disabilities who have been able to make significant achievements in STEM fields. The intent of promoting awareness of, and contact with, these people is to use the student's identity as a person having a disability as a means of demonstrating their potential for achieving success comparable to the role model figure. Methods of delivering this type of intervention can include personal meetings with role models, readings and multimedia video presentations portraying the life and accomplishments of the role model figure, and activities that encourage reflection on the role model's experience to build motivation and self-efficacy. The American Association for the Advancement of Science (AAAS) maintains a registry of STEM professionals with disabilities, which has been used to facilitate interactions between these potential role models and STEM SWDs (see *29*).

Individualized Developmental Advising

One type of intervention that has been employed in a few instances with college SWDs in STEM has been a holistic form of student advising that combines aspects of academic advising, counseling, mentoring, and case management to provide students with a formalized single point-of-contact for support in pursuit of their educational and career goals. Examples of this type of advising within intervention programs for SWDs in STEM majors include the Ability Advisor role developed under OSAA at Wright State University and the Spectrum Support Program (SSP) Coach function implemented at Rochester Institute of Technology in a program focused only on students with autism (*30*).

As opposed to classical prescriptive academic advising that focuses on details of the student's course of study, this activity can be appropriately classified as a form of developmental advising (*31*). Crookston (*32*) described developmental advising as an interaction with students that is concerned not only with a specific personal or vocational decision, but also with facilitating the student's rational processes, environmental and interpersonal interactions, behavioral awareness, problem-solving, decision-making, and evaluation skills. Creamer and Creamer (*33*) noted that this form of advising uses interactive teaching, counseling, and administrative strategies to assist students to achieve specific learning, developmental, career, and life goals. The nature of the typical student-advisor interaction that occurs under the Ability Advising model developed under OSAA was best described by Winston, Ender, and Miller (*34*) as "*a systematic process based on a close student-advisor relationship intended to aid students in achieving educational, career, and personal goals through the utilization of the full range of institutional and community resources. It both stimulates and supports students in their quest for an enriched quality of life. (It) reflects the mission of total student development and is most likely to be realized when the academic affairs and student affairs divisions of an institution collaborate in its implementation.*"

The developmental advising used in OSAA establishes a formal long-term relationship in which students meet with the advisor on a monthly basis (or more frequently, as required). The Ability Advisor focuses on working with the student to iteratively assess individual needs to achieve the STEM educational and career goals. As illustrated in Figure 2, the Ability Advisor typically uses both internal program resources and broad institutional and community resources to help both the struggling student who may need tutoring and assistance in the sharpening of time management and study skills, and the advancing student to provide access to STEM enrichment activities, internships, cooperative training programs, and career preparation interventions. Tools available to the adviser may include intrusive academic monitoring and control of access to incentives. Adviser actions may include assistance with development of personal skills, academic skills, facilitation of STEM work experiences, and preparation for transition to careers and graduate school.

Internships and Research Experiences

Like mentoring, participation in internships and research opportunities is rapidly becoming an integral part of the STEM educational experience at the undergraduate level in STEM majors. Evidence from the general population demonstrates that undergraduates who conduct research show strong improvements in the cognitive skills essential to STEM success such as independent and critical thinking and problem solving (*35*). Moreover, the intellectual gains made through research experiences and internships appear to be greatest for students from underrepresented groups (*36*).

Like members of other underrepresented groups, SWDs entering college often have limited prior exposure to hands-on experiences in STEM, and are likely to accrue similar exceptional benefits from research experiences. Beyond providing opportunities for participation in a broad range of research and development activities performed by scientists and engineers, internships and undergraduate research experiences may play another crucial role in STEM success for SWDs. Full participation in unpaid research work in faculty laboratories, on-campus or industry-based research training programs, and in government science and engineering internships provides evidence to future employers that SWDs are able to operate effectively in laboratories and offices. It also provides SWDs with skills, role models, and mentors that may not have been learned or

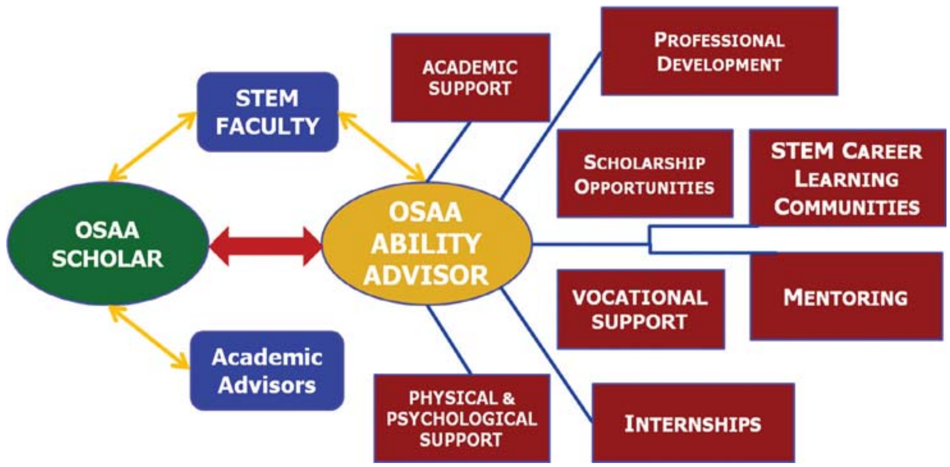

Figure 2. The Ability Advisor Model for Developmental Advising of Students with Disabilities in STEM College Majors.

accessed in a strictly academic environment. Perhaps most importantly, these immersive experiences build a sense of identity and efficacy in the STEM world that are key markers for persistence and success.

The AAAS Project on Science, Technology, and Disability and its flagship ENTRY POINT! Program was a pioneer in promoting internships for college SWDs. Since 1975, the program has placed more than 500 students in STEM internships, and AAAS reports that approximately 90% of these are actively working in STEM fields or pursuing graduate degrees (*37*). In the last decade, NSF and National Institutes of Health (NIH) programs aimed at increasing the diversity of the STEM workforce have begun to include PWDs as an underrepresented group in recruiting for focused STEM research training grants and have supported accessible internship programs as a part of education projects for SWDs.

Non-Cognitive and Personal Skill Development

Problems with psychosocial skills were identified earlier in this chapter as one of the primary barriers to achievement in STEM for SWDs. As a consequence, programmatic interventions and activities are sometimes offered to help SWDs develop a constellation of "soft skills," attitudes, and habits that can be as critical to academic and career success as knowledge and experience with specific science, engineering, or mathematical concepts. Heckman has recently popularized the concept that many students and workers fail not because of intellectual limitations but because of inadequate "non-cognitive skills" (*38*). According to Heckman, these counterparts to knowledge and intellect include traits, characteristics, and abilities such as persistence, self-control, curiosity, conscientiousness, determination, and self-confidence. Heckman's work has shown that college failures are common in students who have failed to fully develop non-cognitive capacities by experiencing and overcoming life and academic challenges requiring effective social interactions, long-term independent effort, and self-determination.

Many SWDs entering college in STEM fields may fall into this at-risk group as an unanticipated result of protective treatment and provision of well-intentioned, but excessive, assistance at school and in the family during their formative years. The resulting lack of self-advocacy, independence, and self-control skills can be reflected in a failure to communicate effectively with college faculty and staff, poor goal setting and time management performance, and inefficient study strategies. Moreover, the vast majority of significant STEM educational experiences and later work activities require an ability to interact effectively in a social context on teams and in collaborative work groups. While not all SWsD have problems in this area, many need specific assistance because of the nature of their disability (e.g., autism spectrum disorder).

The internships and research opportunities described above that immerse the college student in a real world, but supportive, work environment can significantly contribute to improved communication skills, perseverance, self-determination, and self-advocacy that they will need to function as STEM professionals. In addition, several Internet information sources, the use of virtual experiences and modeling, as well as classroom-based or online interactive courses, have been used for directly addressing these issues with college SWDs (e.g., *39*, *25*). One NSF-funded effort at the University of Wisconsin-Stout known as "Soft Skills Hard Science" has focused exclusively on the development of practical psychosocial skills in a research project aimed at assessing the impact of soft skill development through training modules, mentoring, and work experiences (*40*).

Participation Incentives

Competing fields of interest as well as the initial large time and effort demands of adopting a STEM major makes the use of financial or other material incentives an attractive feature for inclusion as a component of intervention programs wishing to maximize recruitment among SWDs and other underrepresented groups. Direct monetary payments or tuition/fee/room/board/service scholarships are one option for promoting participation in intervention programs, staying in a STEM major, or earning good grades. Another alternative used by OSAA is to provide STEM interest awards to SWDs who participate in program interventions such as developmental advising, and engage in co-curricular STEM knowledge and skill development activities. These awards can include research materials and equipment, STEM conference travel, assistive technology, software, or Graduate Record Exam fees.

Stephens and Townsend (*41*) noted that research on the use of financial incentives with college students to promote participation in activities to reduce achievement gaps has produced mixed results. They attribute the lack of impact in some programs to a failure to observe several guiding principles for designing incentives to change behavior. Included among these are that incentives should be used consistently and concretely tied to the behavior of interest, connected with the real behavioral change of interest rather than incidental activities (e.g., application of newly learned study skills rather than attendance at the class), and chosen to be meaningful to the intended population and consistent with the context and purpose of the training or intervention program. The present authors were unable to find published data demonstrating the impact of a particular incentive program on promoting the success of college SWDs in STEM. However, based on this guidance, the details of incentive programs may deserve evidence-based review to ensure that funds are actually reinforcing desired student behaviors leading to STEM persistence and entry into the workforce following graduation.

STEM Enrichment Activities

This category of programmatic interventions encompasses a wide variety of participatory activities that are made available to college SWDs to broaden their extracurricular exposure to STEM fields, concepts, methods, and applications. Generally addressing STEM interest development, academic preparation, and cognitive and psychosocial skill enhancement, enrichment activities can include attendance at scientific conferences, STEM-related service projects, group travel, student social meetings that include STEM professionals, and departmental colloquia. These interactive events and projects can be attended by SWDs either in-person or, increasingly, online.

Extensive research with general high school student populations has shown a close correlation between student attainment, interest and motivation, and participation in this type of enrichment activity that probably continues to apply in postsecondary educational situations (*42–44*). At the college level, students have reported that STEM-related co-curricular activities help them to be successful by providing opportunities to develop student and professional relationships, future career plans, and mentorships (*45*). Huang and Chang (*46*) showed that co-curricular involvement of this sort is also predictive of college persistence. In some cases, where activities require travel or field work in unusual environments, access to enrichment experiences can be limited for students with physical disabilities. However, the development of advanced virtual technologies that permit immersive engagement with scientific field sites and phenomena hold promise for making even these experiences available to all students (*47*).

Career and Graduate School Preparation

This final class of interventions focuses on the ultimate goal of the student's college education, which is successful transition to a career or advanced training. As noted by Nicholas *et al*. (*48*), regardless of the gains made in enrolling and graduating SWDs from postsecondary programs, recent assessments show that the employment rate for college graduates in the U.S. with disabilities is only 50.6%, compared with nearly 90% for graduates without disabilities. Such disparities point to the need to look beyond recruitment and retention strategies to interventions at the college level that bolster the ability of SWDs to transition successfully to the STEM workforce and advanced studies in graduate programs.

During the initial years of college, career exploration activities can serve as a tool to focus on a STEM major, refine interests, and guide early career preparation. In addition, internships and research experiences, especially during the last two years of college, offer a form of embedded training in appropriate behaviors within relevant work environments, and provide direct evidence to future employers of the individual's STEM knowledge and capabilities, ability to work in teams, and fit with the science and engineering enterprise.

In addition to these general experiences, direct interventions have also been implemented to develop practical professional job seeking skills and support SWDs in acquiring the knowledge needed to become both competitive candidates and successful new employees or postgraduate students. Such preparation activities include training and exercises in developing and maintaining a portfolio of STEM experiences and accomplishments, GRE preparation, opportunities for question and answer sessions with current STEM graduate students and representatives from government and industry, interview practice, and graduate school application guidance. The vehicles used to deliver this type of professional development and career readiness training can vary, including one-on-one interactions with an individualized adviser, in-person group events, webinars, and on line resources and learning modules that are available 24/7 (*25, 39, 49*).

A LOOK AT IMPLEMENTATIONS AND OUTCOMES

As a part the research for this chapter, the authors examined a variety of websites and publications created by current and past projects that have used programmatic interventions to increase the number of PWDs preparing for, and entering, STEM careers. Several of the recent projects that have focused these direct interventions on college SWDs are cited in the previous section of this chapter. It was not our purpose, nor do we claim, to have completed an exhaustive analysis of all of these programs and their content or assessed their effectiveness. However, our focused overview yielded a few pertinent observations that may be helpful in considering the direction of future work in the area.

One obvious fact is that these programs vary widely in the degree to which they focus on SWDs at the college level, as well as in the type and number of interventions provided. Most activities conducted by past and ongoing programs appear to have been aimed primarily at high school students to grow their interest in STEM endeavors and prepare them for the college transition, and have only secondarily worked on support for students while they are in college. Common interventions for high school SWDs include STEM summer institutes and camps, pre-college STEM work experiences, and mentoring to achieve these objectives. Such early intervention to improve recruitment to college is certainly a worthy goal. However, by their nature, projects that effectively end as the student transfers to college cannot be expected to have long-term effects on behaviors leading to retention at college, graduation, or success in the transition to the workforce. In funded programs that have included an emphasis on college, the focus has often been on faculty and institutional change rather than direct work with students themselves. Our observation that there has been continuing emphasis in the focus of intervention programs away from college level SWDs is confirmed by an online list of promising practices for growing the representation of PWDs in STEM that is published by one of the longest operating projects in the area (*50*). The listed practices from programs around the country include technological innovations as well as activities aimed at SWDs, educators, and staff at a range of educational levels. Of the 89 practices appearing on the list, only 9 included direct programmatic interventions with college students as some part of the activity.

In programs that have focused on, or at least included college SWDs as some part of the target population, the most common have been those offering some sort of STEM research or work experience. These include NSF Research Experiences for Undergraduates and similar NIH programs offering supervised research training experiences to students. Other popular college student interventions are in-person and online mentoring, psychosocial skill development and career preparation in learning communities or other group events, STEM enrichment activities, and participation incentives. A notable difference among programs is that they vary greatly in the depth and variety of interventions used to enhance student success. While some may use one or two methods, others use a broad range of techniques tailored to the varying needs of the students during their college careers. For example, the AAAS ENTRY POINT! program specializes only in providing internship experiences to SWDs, while the OSAA program as implemented at Wright State University provides an integrated program of interventions that includes nine of the 10 classes of interventions reviewed for this chapter.

A student with visual impairments can perform most lab techniques with the appropriate accommodations and assistive technology.

A second characteristic of intervention programming that emerged from our review was a notable scarcity of publicly accessible data on near and far term outcomes of individual projects. The overarching goal of most of the efforts that have included direct college student interventions has been to build the STEM workforce by increasing the participation of PWDs. Since these programs have been situated within U.S. colleges and universities, outcomes of intervention efforts with college students logically could be expected to be measured and widely reported in terms of improved recruitment, retention, and graduation rates. Nevertheless, we found very little evidence along these lines. A notable exception is the Disabilities, Opportunities, Internetworking, and Technology (DO-IT) program at the University of Washington, which has conducted a longitudinal outcomes study of SWDs who have participated in the various activities it has offered. However, the follow-up data available thus far appears to report achievement primarily for SWDs who have received only pre-college interventions. In considering the limited availability of data on goal-relevant outcomes, it must be recognized that it can be difficult to realize quantitative results of college level interventions in programs that are funded for relatively short periods of time. However, it is possible. Following four years of providing a common set of nine interventions with over 170 college SWDs, OSAA at Wright State University has recorded steady quantitative increases in the number of SWDs in STEM majors within the institution as well as higher student retention rates and STEM graduation rates for participating students when compared with local and national benchmark data for nondisabled students.

A final observation that surfaced from our review of intervention programs is that research and implementation projects over the past 20 years have not yet provided us with a coherent, evidence-based literature addressing the question of why SWDs continue to be underrepresented in STEM, or clear descriptions of the type and nature of the interventions that are most effective in improving inclusion in STEM. A workshop report issued jointly by NIH and NSF (*51*) argued that among the most significant challenges to increasing the representation of PWDs in the STEM workforce is a "*lack of good—or even passable—data*" on how and why SWDs do not advance as far as their peers. In a similar vein, Lewis and Farris (*52*) reported that research on best practices in the recruitment of SWDs in STEM is nearly nonexistent, as recruitment programs are either scarce or not well documented. To the criticism expressed by these authors, we would add that the problem is compounded by the absence of substantial scientific evidence on what types of interventions can work to address this rupture in the STEM pipeline that occurs during the college years and in postgraduate endeavors. In essence, knowledge about the detailed content and methodology used in interventions with college SWDs in STEM, goal-oriented results of their impact, and supporting evidence for replication of practices purported to be effective is limited and lacks uniformity and precision of reporting. This state of affairs could limit the success of future implementations. However, as discussed by Grant *et al*. (*53*), it is not an uncommon problem in the field of educational intervention.

RECOMMENDATIONS

The ideas and conclusions presented in this chapter were discussed with the participants in a workshop at Purdue University held in May 2013 to address the issue of increasing the representation of PWDs in STEM careers using interventions, technologies, and dissemination strategies focused on postsecondary SWDs. The following recommendations are drawn from the examination of programmatic interventions conducted by the authors and the results of these discussions with workshop participants.

There is a broad need for ecologically valid research to test and refine interventions at the college level. This research should seek to define the fundamental characteristics of those intervention approaches and methods that lead to high levels of entry to STEM careers among PWDs. It should provide results and outcome data that reflect attainment of long-term objectives (e.g., graduation with STEM degrees, entry into the STEM workforce, admittance to graduate school) and closely associated short-term achievements (e.g., college retention, GPA, participation in STEM co-curricular and external endeavors). This research must also serve to build a coherent body of knowledge, theory, and evidence-based practices that will make an effective case for future investment in programs to advance the success of SWDs in STEM.

As a part of this research agenda, renewed efforts are needed to intentionally include STEM students and professionals with disabilities in the design of interventions and of studies to test their effectiveness. Moreover, to achieve the level of ecological and external validity needed to support useful theory building and create interventions suitable for broad application, research should be embedded in appropriately scaled implementation environments where multiple interventions can be compared in the context of a common set of environmental and academic conditions, and where historical and contemporary baselines can be established for major outcome variables. Studies conducted with very small numbers of SWDs in isolated, unreproducible educational environment are unlikely to make significant contributions to answering the critical questions in this area.

Among the types of research needed are comparative studies that use outcome-focused evidence derived from widely-accepted objective and qualitative measures to identify interventions that work and those that should be discarded in future implementations and scale up efforts. Additional studies are needed that offer insights into the unique institutional and curricular roadblocks experienced by students with specific types of disability and the interventions that succeed in enabling student to overcome them. Some of the specific areas for future research and development identified by participants in the Purdue workshop included studies to: (1) address the need for, and effective composition of, programs that include multiple intervention components; (2) investigate methods to build STEM identity in college SWDs and the characteristics of interventions that reinforce STEM identity; (3) identify the preparation and training requirements for effective mentors (especially peer mentors) of college SWDs in STEM; (4) assess the qualities of effective role model experiences for college SWDs in STEM; (5) define effective interventions for improving advanced non-cognitive and psychosocial skills for SWDs in STEM including teamwork and leadership; and (6) develop effective interventions to support the growing number of college students that have good STEM aptitude but are at high risk of failing to succeed in college and career entry as a result of disabilities that affect social interactions.

The recommendations outlined above appear to set a daunting agenda for intervention researchers and those wishing to build effective programs that will support the success of college SWDs in becoming a part of the national STEM enterprise. However, the magnitude of the task may be diminished to some extent by the adoption of a more encompassing view of the nature of the problem and potential sources of useful knowledge to guide this work. The barriers to STEM inclusion faced by college SWDs include some factors uniquely associated with specific disabilities as well as elements that are shared by other underrepresented groups in STEM including racial and ethnic minorities. Because of this, the focus of intervention research and development for SWDs should be opened to embrace a true “Science of Broadening Participation” that would seek to identify both common and exceptional barriers to success faced by underrepresented populations in STEM, and take maximal advantage of the theories, findings, and evidence-based methods from this wider community of scholars. By identifying effective interventions that serve the shared needs of underrepresented groups of individuals, more efficient resource allocation decisions can be made to build capacity using evidence-based intervention models, to invest in new development to address unmet needs, and to see that all who aspire to an education and career in STEM are given the opportunity to succeed.

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College Students with Disabilities in STEM: Expanding Opportunities by Enhancing Communication of Evidence-Based Information with Stakeholders

CHAPTER
3

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Appropriate communication of evidence-based approaches and methods is essential among all stakeholders concerned with the inclusion of individuals with disabilities in STEM higher education and careers.

INTRODUCTION

This chapter focuses on enhancing communication with stakeholder groups for the purpose of promoting the success of students with disabilities in science, technology, engineering, and mathematics (STEM), particularly in college. The authors discuss those factors that impact student success in postsecondary education, approaches for ensuring STEM access for students with disabilities, and the characteristics of communication types that promote change. They also explore the content needs for specific stakeholder groups, share exemplary practices, and suggest implications for further research and practice.

BACKGROUND

To fill increasing numbers of positions in STEM (*1*, *2*), the United States must draw from a talent pool that includes all demographic groups, including those with disabilities (*3*). More individuals with disabilities are completing high school and attending college with an initial interest in STEM similar to that of their peers without disabilities. However, students with disabilities (SWDs) experience far less success in STEM than students who do not have disabilities (*4–6*). Those with disabilities who are also minorities, female, and/or veterans face multiple challenges (*3*, *7–9*).

Success stories in STEM fields (for example: *10*, *11*) demonstrate that opportunities do exist for SWDs who are prepared to overcome barriers imposed by, among other factors, inadequate preparation; low expectations and negative stereotyping; inaccessible curricula, web resources, science laboratories, and equipment; and inadequate accommodations and support services. Researchers and practitioners have found that factors impacting postsecondary student success are related to the individual, the institution, and the external community (*12*, *13*). Berge and Haung (*14*) propose a holistic, customizable model of retention that encourages consideration of the interconnectivities among factors such as those presented in Table 1.

Evidence suggests that college retention issues for SWDs are similar to those for other students (*15*). Drawing on Berge and Haung's multifaceted conceptualization of retention to promote the success of SWDs in STEM, interventions focused on students, institutions, and other stakeholders should strive to:

- encourage commitment (e.g., to STEM success on the part of the student, student service units, and the institution).
- enhance integration (e.g., by transforming existing STEM programs to be more inclusive of SWDs).
- improve delivery systems (e.g., for both general student support services and specialized services for SWDs).
- increase person-environment fit (e.g., through both systemic changes in STEM programs and services and reasonable accommodations for students).
- improve outcomes (e.g., with measures that include STEM degree attainment and program/course/service ratings of SWDs).

Within the context of this chapter the authors embrace a broad definition of "communication," namely, "the activity of conveying information through the exchange of thoughts, messages, or information, as by speech, visuals, signals, writing, or behavior. It is the meaningful exchange of information between two or a group of persons" (*16*). Communication materials and dissemination vehicles include, but are not limited to, journals, brochures, and other printed materials;

video presentations, audio recordings, visual aides, and multimedia; one-to-one and small group conversations; in-person presentations; hands-on activities; role modeling; and websites, e-mail, social media, and online courses.

The intended outcome of the communication in this chapter is utilization. With respect to translating new knowledge into utilization, leaders are increasingly asking questions about the quality of evidence (research findings or other information) that is being communicated to others in the field (*17*). When an audience is expected to utilize information, they are likely to be interested in knowing if the strategy communicated works within a specific setting or context. Researchers for the What Works Clearinghouse—hosted by the U.S. Department of Education's Institute of Education Sciences (*18*)—have worked to identify and define methods and quality indicators for use in studies of instructional strategies and interventions. Much of this attention is focused on the "research-to-practice gap" wherein many research-supported practices are underutilized.

Ideally, utilization of communication content results in positive change. As outlined by Levy and Merry (*19*), change can be viewed from three perspectives:

- the reason for change—What might motivate specific stakeholders to make the desired change?
- the content of change—What content needs to be communicated to specific stakeholders so that they can make the desired change?
- the process of change—What communication methods will motivate and equip stakeholders to make the desired change?

In the next section, the authors discuss motivating influences for specific stakeholders to change and what information they would need to initiate such change.

MOTIVATION AND CONTENT FOR CHANGE

Stakeholder motivations, belief systems, interests, and needs are addressed in effective communication with the group (*20*, *17*). This includes presentation of types of evidence most valued by the audience. Of course, a gap exists between what constitutes quality evidence and meaningful research from the perspective of researchers, policymakers, funders, and others who may have a wide variety of responsibilities, experiences, and perspectives. To visualize this gap, consider the disparate needs of a practitioner serving a specific student in a busy classroom and an Institute for Education Sciences (IES) reviewer considering numerous and voluminous funding applications. The teacher values immediate adaptability, and cannot wait for the results of rigorous research before implementing practices in the classroom, nor do they have the resources to conduct randomized trials of a promising practice using control groups. On the other hand, the IES reviewer may only value, and therefore fund, projects that employ rigorous research methods. We solicited suggestions from participants in interactive sessions at the "From College to Careers" workshop described in the introductory materials of this publication regarding motivations and content for change toward improved STEM outcomes for college SWDs for key stakeholder groups. Some workshop participant input is incorporated in the following pages.

Students with Disabilities, Parents, and Other Advocates

Motivation. College SWDs might be motivated to pursue STEM fields in order to explore interesting and challenging problems, gain self-satisfaction, demonstrate their abilities, and/or contribute to discovery. Parents and other advocates for SWDs may have similar motivations, in addition to gaining peace of mind regarding what the future holds for the individuals for whom they are concerned.

Content. Workshop participants suggested that content of communications directed at SWDs should focus on self-determination skills (in particular, self-advocacy skills in postsecondary education); science and mathematics academic knowledge; knowledge of and access to accessible computing and science equipment, role models, resources and how to access them; and knowledge of STEM career fields.

PERSONAL VARIABLES	INSTITUTIONAL VARIABLES	CIRCUMSTANTIAL VARIABLES
• **Demographic Variables:** Age, gender, ethnicity, socio-economic status, parent educational levels and expectations • **Individual Variables:** Academic skills and abilities, motivation, goals, commitment • **Prior Educational Experiences:** Record of academic achievements, prior school experiences	• **Bureaucratic Variables:** Mission, policy, budgeting/ funding, institutional awareness, participation • **Academic Variables:** Structural, normative systems • **Social Variables:** Systems and mechanisms for social integration	• **Institutional Variables External to the Institution:** Academic, bureaucratic, social • **Student Variables External to the Institution:** Life, work, family, other circumstances

Table 1. Berge and Haung Model of Retention.

Researchers and practitioners studying effective ways to bring students from underrepresented groups into STEM fields have found that:

- students have little access to peers and mentors from the underrepresented group of which they are a part
- both academic and non-academic (e.g., cultural, social) challenges faced by students should be addressed through interventions
- motivational activities are necessary to recruit students without existing interests in STEM
- comprehensive retention interventions produce more positive outcomes than isolated efforts (*21–30*).

To succeed in a college environment in a STEM field,SWDs need to develop prerequisite academic skills, STEM knowledge, and self-determination skills (*31*). “Self-determination” has been defined as “a combination of skills, knowledge, and beliefs that enable a person to engage in goal-directed, self-regulated, autonomous behavior. An understanding of one’s strengths and limitations together with a belief in oneself as capable and effective are essential to self-determination” (*32*). Besides advocating for themselves, individuals with disabilities can learn to advocate for other students with disabilities similar to and different from their own.

SWDs should learn to use computing technology and science equipment in ways that maximize their independence, productivity, and participation in college and facilitate a successful transition to employment. Technology can be used to support peer and mentor relationships, access to electronic information, participation in science laboratories, communication in class discussions, self-advocacy practice, and work-based learning opportunities. SWDs can also gain knowledge and skills through campus activities, internships, and other on-site activities.

Content delivered to parents and advocates should be similar to that for SWDs so that they can guide students in their pursuit of STEM. In addition, content should help them understand a child’s capabilities and how to engage with other parents and advocates.

Educators, Administrators, and Their Professional Organizations

Motivation. When educators feel a need and readiness to learn something, they are more likely to choose to participate in professional development opportunities (*33*). Workshop participants suggested that educators might be motivated to encourage SWDs to pursue STEM fields because of a desire to promote the success of *all* students, to implement pedagogical change to reach a diverse group of students, to diversify STEM fields, to fulfill professional responsibilities, to gain recognition, to meet legal requirements, to make their jobs more rewarding, to secure grant funds, and to locate topics for research and publication.

Content. Workshop participants proposed that content for these stakeholder groups should focus on conditions that have led to the underrepresentation of individuals with disabilities in STEM fields; assistive technology, accessible laboratory equipment, and academic accommodations that make STEM accessible to individuals with disabilities; best practices for inclusive teaching; legal obligations; research; and resources.

Input from workshop participants is consistent with evidence presented in the literature. For example, postsecondary faculty often report—and SWDs confirm (*34*)—that they do not know about the policies and procedures they should employ, legal obligations, accommodations, how to communicate with SWDs, and/or campus resources (*35–43*). Some do not understand that appropriate accommodations provide equal opportunity, not an unfair advantage.

To ensure equal opportunities, physical environments, technology, services, and courses at educational institutions need to be welcoming and accessible to SWDs. Broadly speaking, two approaches—reactive and proactive—have been taken by institutions to reach this goal through accommodations and universal design (UD), respectively. Accommodations are adjustments to an educational product or environment when it is not accessible to a specific student, for example, providing a sign language interpreter to translate a video presentation for a student who is deaf. On the other hand, captioning the video so that all students can benefit from the enhancement is an example of UD. The captions not only benefit students who are deaf, but also English language learners and those viewing the videos in noisy (for example, a student union building) and noiseless (for example, a library) environments. UD, defined by the Center for Universal Design (CUD) as “the design of products and environments to be usable by all people, to the greatest extent possible, without the need for adaptation or specialized design” (*44*), challenges society to construct a world where everyone can participate with maximum independence. Promoting UD is consistent with the “social model” of disability and other integrated approaches within the field of disability studies (*45*, *46*) where variations in abilities—like those with respect to gender, race, and ethnicity—are considered a natural part of the human experience.

The directors of twenty-one projects to prepare faculty to effectively teach SWDs, all funded by the U.S. Department of Education Office of Postsecondary Education (OPE), felt it was critical that faculty learn about UD principles and their application to the design of technology, instruction, services, and physical spaces; accommodations for SWDs; and legal rights and responsibilities (*47*), with examples tailored to specific audiences.

Content delivered to administrators should encourage them to establish policies, standards, procedures, and training/support that work to ensure that educational products and environments are accessible to everyone, including SWDs. Educators, librarians, science laboratory managers, and technology leaders should procure accessible computers, software, and laboratory equipment; purchase appropriate assistive technology; and support SWDs in their use.

Content delivered to professional organizations, particularly those that attract STEM faculty, should encourage the inclusion of individuals with disabilities in STEM through the publication of relevant articles in professional journals, offering presentations and exhibits at conferences that encourage members to employ UD practices, encouraging members to employ UD in their practices, and making their events welcoming and accessible to individuals with disabilities. Professional organizations can also promote the inclusion of accessibility issues in the evaluation of educational entities, such as in assessments of university quality.

Service Providers

Motivation. Service providers—such as vocational rehabilitation and disability services staff—might be motivated to change practices to more effectively encourage and support SWDs in STEM by both increasing awareness of legal concerns regarding equal access and influencing their desire to fully support their clients to reach their full potential.

Content. Content delivered to service providers should focus on conditions that have led to the underrepresentation of individuals with disabilities in STEM fields, challenges SWDs face in pursuing STEM, assistive technologies, accommodations that make STEM fields accessible to individuals with disabilities, and financial and other employment benefits to pursuing a STEM career.

Technology Companies, Developers, and Support Personnel

Motivation. Technology companies, developers, and support personnel might be motivated to change practices in order to help SWDs pursue STEM by the possibility of selling more products, particularly to educational institutions that are required to make their programs and resources accessible to qualified individuals with disabilities. They may also develop accessible products because of a sense of goodwill and fairness or to promote a positive image for their companies.

Content. Content shared with these individuals should include information about the challenges individuals with disabilities face in using computing and scientific equipment, accessible design strategies, and the availability of technical standards and guidelines regarding accessibility.

Employers, Job Coaches and Placement Personnel

Motivation. Employers and job exploration and placement personnel might be motivated to change practices in order to more effectively encourage and support individuals with disabilities in STEM by a sense of fairness, to meet their legal responsibilities regarding nondiscrimination, and by a desire for a diverse workforce.

Content. Content delivered to this stakeholder group should specifically include information about legal issues regarding employment of people with disabilities, assistive technologies and other accommodations that make STEM accessible, best practices, and the value of a diverse workforce that includes individuals with disabilities.

Researchers

Motivation. Researchers might be motivated to conduct research related to the participation of individuals in STEM fields if they were to better understand inequities, for this group, relevant social justice issues, implications regarding diversity in STEM fields, and the potential applicability of evidence-based interventions for other underrepresented groups to individuals with disabilities.

Content. Content for researchers should promote understanding related to the underrepresentation of individuals with disabilities in STEM, what research has been done previously in the field, and directions for further research that have been identified in the literature. Researchers can promote utilization of findings by relating them to practical applications for key stakeholder groups. The quality and relevance of research can be improved by involving potential users of the results in planning and implementing the research design itself (*17*).

Policymakers and Funding Agencies

Motivation. Policymakers and funding agencies might be motivated to implement practices that encourage and support SWDs in STEM studies and careers due to a desire to ensure that equal opportunities are available to all citizens, to increase the number of STEM workers, to diversify STEM fields, to achieve economic development goals, to remove a financial burden from the government, to gain political advantage, and to respond to public pressure.

Content. Content for policymakers and funding agencies should illuminate conditions that have led to the underrepresentation of individuals with disabilities in STEM fields, assistive technology and other accommodations that make STEM accessible to individuals with disabilities, strategies that have the potential to correct inequities, how supporting SWDs meets

A student with upper extremity mobility impairments using a light microscope.

societal needs, and how interventions can lead to a large return on investment.

PROCESS FOR CHANGE

Communication strategies should be informed by an understanding of the change process. The ADKAR people-oriented model for promoting and sustaining change (*48*) recommends that implementation align with five characteristics relevant to each individual—Awareness, Desire, Knowledge, Ability, and Reinforcement. Below, each characteristic is paired with an example related to working with postsecondary faculty.

- Awareness of the need to change. Make sure faculty understand why change is needed to make science more accessible and what will be the result of the change.
- Desire to participate and support change. Motivate faculty to make changes toward more inclusive instruction and accessible course materials and science equipment.
- Knowledge of how to change (and what the change looks like). Ensure that science faculty know how to make specific changes, such as how to make their course web resources fully accessible and usable by all students.
- Ability to implement the change on a day-to-day basis. Give science faculty the information, resources, and training they need to implement change.
- Reinforcement to keep the change in place. Implement a system to sustain the change, perhaps through ongoing communication in a faculty learning community.

The AKBAR model can be applied to communication with other stakeholder groups as well. For example, interventions for SWDs are reported in the “Interventions with College Students to Increase the Representation of Persons with Disabilities in STEM Careers” chapter of this publication (see page 31).

Using multiple modes of communication—such as online communication, websites, printed documents, and on-site training—can maximize utilization of the content (*17*). The National Center for the Dissemination of Disability Research (NCDDR) (*17*) concludes that effective communication plans articulate goals of the communication, specific objectives, characteristics of the potential users of the content, information sources that the stakeholder group respects, mode(s) for delivery of the content, measures of success of the communication, promotion strategies, and potential barriers to communication efforts.

Researchers have concluded that: one-time workshops rarely result in utilization (*49*); practice, feedback, and coaching are critical (*50*); learning communities can play an important role in training (*51*); and both on-site and online communication should be implemented (*52*, *53*).

Some researchers and evaluators have shared the results of communication with postsecondary faculty and administrators for the purpose of increasing the success of SWDs. Getzel and Briel (*47*) summarized the experiences of 21 projects funded by OPE to prepare faculty to effectively teach SWDs. The projects utilized brochures, videos, websites, and on-site training. Some training was offered within regularly scheduled faculty meetings, some as standalone events. The three top challenges in providing the training were time constraints, lack of a perceived need for training, and lack of administrative support. Respondents encouraged other campuses to build collaborative partnerships with faculty and to offer face-to-face, online, and print options for gaining knowledge.

Some research and evaluation data reveal a positive correlation between disability-focused training and changes in faculty attitudes and perceptions about SWDs (*54*). For example, Sowers and Smith (*55*) reported positive results from training health sciences educators. Faculty developed more positive perceptions of disability and perceived that they had increased knowledge about disability. Videos of health care professionals with disabilities appeared to be particularly impactful in this area. The researchers attributed some of their success to tailoring the training to specific disciplines and offering a wide variety of training options. Moon, Utschig, Todd, and Bozzorg (*56*) also report positive outcomes from on-site training and online resources designed to enhance the skills of STEM faculty when working with SWDs.

Some evidence suggests that training leads to changes in behavior. Park, Roberts, and Stodden (*57*) reported positive results of a three-day summer institute for instructional faculty in enhancing their attitudes, knowledge, and skills in meeting the needs of SWDs. Participants reported that after the institute they were more ardent in working with disability support services to provide accommodations for SWDs, took steps to make course materials more available and accessible, and shared content from the institute with other faculty.

Research and evaluation data reveal a link between disability-focused training and outcomes for SWDs such as higher grades relative to other students. One research effort undertaken in the DO-IT AccessCollege project (*58*) tied faculty training in UD to higher grades earned by SWDs. Specifically, using a quasi-experimental 2X2 research design, student course grades were collected at two points in time—before the training was offered (“pre”) and after the training was offered (“post”)—in classes taught by faculty who received UD training and in classes taught by “matched” faculty who did not receive training. The grades of SWDs in classes taught by faculty who received training increased more than for those in courses taught by untrained faculty, whereas the performance of students without disabilities stayed about the same. After instructors were trained in UD, the performance levels of students with and without disabilities were close to the same.

Examples of communication practices that have been undertaken to promote the success of SWDs in STEM are listed below. Evidence that supports their efficacy with respect to utilization varies greatly.

- On-site training/meetings focused on STEM and disability (*59–61*)
- Biographies and online resources for SWDs that address STEM access (*10*, *62–69*)
- Training/professional development materials (*18, 70–75*)
- STEM curriculum that includes accessibility topics (*76*)
- Comprehensive websites focused on STEM and SWDs (*5, 65, 66, 77, 78*)
- Searchable databases (*79*)
- Printable brochures, short publications, and briefs (*22, 80–88*)
- Learning and mentoring communities that support STEM SWDs (*89–91*)
- Communities of practice that promote the inclusion of SWDs in STEM (*51, 92)*
- Articles about STEM participation published in disability/diversity-related publications (*56, 91, 93–10*1)
- Articles published in periodicals that cover the intersection between disability/diversity and STEM/STEM instruction (*102, 103*)
- Articles about STEM participation of SWDs published in general education periodicals (*104–106*)
- Articles about disability published in STEM and STEM education periodicals (*20, 107–111*)
- Special issues of journals focused on STEM and SWDs (*112*)
- Books and book chapters that cover STEM and SWDs (*11, 22, 113*)
- Video presentations (*114–118*).

Disability-related conferences that have included presentations on STEM include the annual conferences of the Association on Higher Education and Disability and the Council for Exceptional Children, as well as the Pacific Rim International Conference on Disability and Diversity. STEM-related organizations that host conferences that regularly, occasionally, or potentially have presentations regarding SWDs include the American Association of Physics Teachers, American Society for Engineering Education, Association of Mathematics Teacher Educators, Association for Science Teacher Education, Computer Science Teachers Association, National Association of Biology Teachers, National Association for Research in Science Teaching, National Council of Teachers of Mathematics, and National Science Teachers Association.

IMPLICATIONS FOR RESEARCH AND PRACTICE

To effectively increase the STEM participation of individuals with disabilities, funding and resources should be made available so that all stakeholders have access to content tailored to their specific needs using communication methods most appropriate for them. Drawing from stakeholder needs and motivations, challenges to implementing change, and exemplary practices discussed in this chapter, the authors recommend that multiple channels of communication be used to promote the following:

- SWDs with current or potential ability or interest in pursuing STEM should be given the necessary online and on-site support to earn a degree in STEM. Parents and other advocates should be included in these efforts
- Educators should have access to tailored content so that they can effectively encourage and support SWDs in STEM fields
- Postsecondary administrators should promote the adoption of UD practices through the disability services office, center for teaching and learning, information technology training center, and/or other relevant units
- Faculty and administrators should promote the accessible design of educational products by voicing accessibility concerns to government regulatory agencies and product developers, purchasing products that are accessible to students with a wide range of abilities, using accessible technologies, and teaching disability- and/or UD-related content in their courses
- UD and other disability-related issues should be addressed in existing STEM-related websites and other resources, and included in publications regarding STEM education
- Editors of STEM publications should encourage the contribution of articles related to SWDs, and editors of publications focused on disability should encourage the submission of articles related to STEM
- Industry should be encouraged to hire a diverse workforce, involve consumers with a wide range of abilities in product design and usability testing, and make accessibility features readily apparent as well as train sales representatives about these features
- Employers and job placement personnel should learn how assistive technologies and worksite accommodations can make STEM possible for individuals with disabilities, how to effectively communicate with an intern or employee about his/her disability, and how to make choices that maximize an employee's independence, productivity, and participation
- Legislators and policymakers should disseminate information about current laws, policies, and resources tailored to the needs of various stakeholders as well as identify, share, and correct inconsistencies and gaps in legislation and policies that impact STEM participation of individuals with disabilities
- Agencies should require the employment of accessible/UD principles in projects they fund.

The content presented in this chapter also points to a need to get UD on the research agendas of STEM educators as well as researchers in human factors, user interface, information sciences, education, and usability. There is a need for research and communication of findings regarding:

- baseline data on the knowledge, skills, and effective communication approaches for specific stakeholder groups
- the identification of barriers to STEM for students with specific disabilities and interventions that further their success in academic studies and careers
- longitudinal data involving the long-range effectiveness of interventions and other success factors in helping students gain access to STEM studies and careers
- the efficacy of the application of UD principles in reducing the need for disability-related accommodations in STEM
- how the goals, content, and strategies of a professional development initiative can effectively produce specific changes in the educational experiences of SWDs in STEM fields
- how STEM industry personnel and consumers can work together to create more economically viable products and environments that include UD features.

CONCLUSIONS

Much can be done to enhance the communication of what is known about SWDs and STEM with stakeholders that include SWDs, parents, educators, administrators, service providers, technology companies, developers, employers, researchers, policymakers, and funding agencies. The authors of this chapter suggest that efforts be increased to reach stakeholders with the content they need and in formats that will motivate them to make positive changes toward increasing the participation of individuals with disabilities in STEM fields. Such efforts have the potential to expand and diversify the STEM workforce and improve these fields with the expertise and perspectives of people with disabilities.

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On the Sustainability of Programs for Students with Disabilities: Observations and Practical Ideas

CHAPTER
4

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Equal to the development of effective programs to promote the inclusion of PWDs in STEM disciplines is the need to sustain and grow these programs for long-term success.

ABSTRACT

Some believe that demonstrated need coupled with established efficacy is sufficient to justify establishment and continuation of educational services and programming for students with disabilities (SWDs). Although perhaps a comforting supposition, one can argue that in practice this has not been the case. Further, in a climate of dwindling resources, arguments based upon normative ethics alone—as correct as they might be—are unfortunately likely to become even less persuasive. In this chapter, we examine current trends in support of the SWD community to establish both a baseline of need and an understanding of programmatic support as they existed in early 2013. We then provide suggestions to advance establishment and sustainability of programs for increasing SWD science, technology, engineering, and math (STEM) participation in particular and any other underrepresented group in general.

The authors of this chapter collectively operate from the premise that appeals to normative ethical reasoning are not enough to consistently initiate or sustain programs to increase representation of SWDs in STEM fields. We define "normative ethics" as philosophical reasoning grounded in how people and societies should act to maintain ethical right. The inadequacy of ethical reasoning to effect action can be troubling, in at least two significant ways.

First, one can correctly view increasing SWD representation in STEM fields as a civil rights issue with supportive actions easily justified by normative argumentation. Although there is still far to go, it is undeniable that normative argumentation, sometimes appearing under the moniker of "raising awareness," has had real impact on advancing inclusivity of underrepresented demographics. To those who have, and continue to fight civil rights battles, our supposition may seem to be a denial of the utility of shining light on what is in fact wrong and what in fact should be corrected. Suggesting that "advocacy is not enough" may fly in the face of persons whose personal and group identities are tightly bound to a justifiable expectation that advocacy can work. However, we are not denying the utility of advocacy, but rather, shining light on the question of whether there are any other tools that we're not using. The tools we have been using haven't worked well enough—and so we ask "what now?"

Second, we exist in a climate of dwindling resources where not every worthy cause will garner appropriate attention and support. It is unfortunate, but realistic, to recognize that there simply will not, in the short or medium terms, be enough economic resources to correct all the wrongs that normative ethics would dictate. In such an environment, there simply aren't enough resources to support all worthy programs and activities. A cynic might suggest that resource poor environments pressure policy makers to offer round robin "carrousel" support to various undertakings. In such a situation, advocacy may provide a ride on the carrousel, but perhaps for only one lap around. After that lap, pressure to set aside that program due to perceived more visible and vocal priorities can cut the ride short. Policymakers may not necessarily have bad intent, but are subject to the pushes that can emerge from complex systems. If we intend to make progress for SWDs, we need to be cognizant of these conditions and augment advocacy with practical strategies designed to keep programs on the carrousel for more than one ride.

So now the question is, if advocacy based on normative ethics is not enough, what is the most appropriate course of action? Here we present some provisional strategies. For sake of discussion, we'll presume that normative arguments will "get us on the carousel" but won't be enough to keep us there. From that premise, the remainder of this chapter consists of three parts. First, we examine the current state of affairs with respect to existing support for SWDs and make clear normative arguments to establish need. This corresponds to "getting on the carousel." Second, we draw from existing literature and expertise in sustaining educational programs to generate sustainability strategies. This corresponds to "staying on the carousel." Finally, we suggest general strategies might be applied to programs for SWDs.

GETTING ON THE RIDE: A CASE FOR ACTION

Persons with disabilities (PWDs) are severely underrepresented in STEM fields. This lack of representation can be seen as both a civil rights issue and an economic issue. PWDs are underrepresented within the workforce in general and are not being adequately prepared for the best STEM jobs in particular. It has been noted that PWDs do not attain their educational goals, and experience unemployment or underemployment (*1*). Employment outcomes for PWDs have not improved since 1990 and between 2008 and 2010, workers with disabilities left the workforce at five times the average rate (*2*). Current Department of Labor statistics (3) show a labor force participation rate of 20.5% and an unemployment rate of 14.1% for PWDs compared to 69.1% and 7.1%, respectively, for persons without disabilities. The median salary gap for scientists and engineers with disabilities ranges from 4% for people younger than 29 years old to 13% for the prime earning period of 40 to 49 years old (*4*). The most recent forecast by the U.S. Department of Commerce predicts a 17% increase in STEM jobs between 2008 and 2018 with 2/3 requiring at least a college degree (*5*) (compared to a 9% increase in non-STEM jobs with 1/3 requiring a degree.) To domestically meet this demand of more than one million new jobs, we must fully engage the entire U.S. talent pool.

Of the civilian non-institutionalized population (data from 2006), 7% of people between 16 and 20 years old, and 13% of people between 21 and 65 years old, self-identified as having a disability (*4*). Of the 16- to 20-year-old population, 1.3% identified as having a sensory disability, 1.6% a physical disability, and 4.7% a mental disability. The 2006 percentages are consistent with a 1997 estimate that 13.4% of the U.S. population in the critical age group between 18 and 44 years of age has a disability (*6*). The Individuals with Disabilities Education Act (IDEA) impacted 8.6% of the total U.S. population (13.8% of public school attendees) aged 3–21 years in 2006 (*7*).

Since the passage of the Americans with Disabilities Act (ADA) in 1991, there has not been a statistically significant increase in STEM doctorates earned by U.S. citizens or permanent residents with disabilities as a percentage of total STEM doctorates earned by U.S. citizens or permanent residents (Fig. 1). Including U.S. doctorates earned by foreign national students, U.S. citizens or permanent residents with disabilities earn 1.0% of STEM doctorates awarded by U.S. Institutions or 0.74% if psychology and the social sciences are removed from the definition of STEM (*4*). This rate of graduate degree attainment is far below the population proportion of SWDs. (Note: after 2010 the reported number of earned doctorates by SWDs doubled because questions defining disabilities were revised, however the revised values are still below proportional representation (*8*).)

SWDs entering college and graduate school are interested in STEM fields at the same proportion as students without disabilities (21.7% to 23.1% in college, 20.3% to 21.3% in graduate school); however the attrition rate at each stage of education is greater for SWDs (*4*). Representation among STEM undergraduate and graduate students drops to 10% and 6.7%, respectively (*4*). The number of enrolled graduate SWDs (6.7%) is comparable to the number of graduate students who are African-American (7.1%) or Hispanic (6.3%) and greater than the number of graduate students who are Native American (0.6%) (*4*). However, in STEM fields from 1999 to 2006, the rate of earned doctoral degrees was 4.6% for Hispanic students, 4.3% for African-American students, 1.02% for SWDs, and 0.5% for Native American students. This equates to a 30% to 40% decline in proportional representation for Hispanic and black students from the start of graduate school to earning a doctorate degree and an 80% decrease for SWDs.

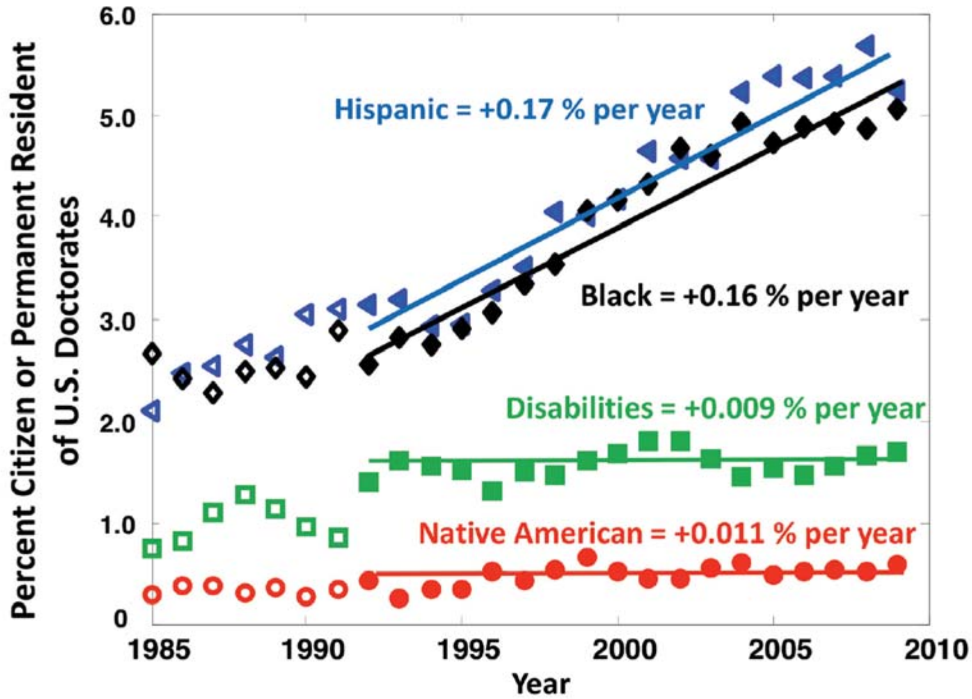

Figure 1. Recent trends of doctorates issued in the United States based on race and disability.

The demographic data point toward SWDs taking alternative paths towards graduate degree attainment relative to students without disabilities. The National Longitudinal Transition Study – 2 (*9*) indicated large differences in persistence and intensity of enrollment among students with and without disabilities in all disciplines. SWDs were slightly less likely to ever have attended a postsecondary institution than students without disabilities (60.1% v. 67.4%); however, SWDs were much less likely to have been enrolled in postsecondary education the two years prior (33.6% v. 51.2%) or at the time of the interview (15.1% v. 28.3%) and were twice as likely to have attended 2-year or community college (44.2% v. 20.6), while half as likely to attend a four-year institution (18.8% v. 40.2%) (*9*). The National Science Foundation presented a more equitable distribution for students in STEM where SWDs are still slightly more likely to have attend two-year institutions than persons not identifying as having a disability (47% v. 42%) and are more likely to attend college part-time (63.8% v. 58.2%). Across all disciplines SWDs were less likely to complete a four-year degree than students without disabilities (34.2% v. 51.2%) (*9*). In graduate school, STEM SWDs tended to be older, with only 7.5% younger than 23-years old verses 17.6% of students without reported disabilities. STEM graduate SWDs were also less likely to be supported on Research Assistant funding (16.4% v. 24.4%) (*4*).

There are, no doubt, numerous contributing causes to the lack of progress realized for degree attainment for PWDs in STEM fields. Prominent among potential factors is the differential emphasis placed by federal agencies on the performance and persistence of SWDs relative to other underrepresented groups. Of the programs listed in the 2010 Federal STEM Education Inventory Data Set as "Institutional Capacity" or "Postsecondary STEM," $378.3 million is dedicated to improving the performance and persistence of underrepresented minorities while only $19.6 million is directed to PWDs; a 19:1 ratio. In other words, PWDs receive 5% of the support while comprising 30% of the underrepresented population. Programs such as the National Science Foundation's Louis Stokes Alliance for Minority Participation (LSAMP) at $45 million, the National Institutes of Health's Research Initiative for Scientific Advancement (RISE) at $24 million, and the National Institutes of Health's Minority Access to Research Careers – Undergraduate Student Training in Research Development (MARC-USTAR) at $21 million all have budgets bigger than the total federal support of postsecondary STEM programs for PWDs. In fact, the largest program targeting PWDs, NSF's Research in Disability Education (RDE), at $7 million in 2010, is currently suspended pending reorganization. In addition, RDE focuses on model building of projects, not sustained funding of successful projects with demonstrated impact. Through programmatic support, federal agencies set the national priorities for diversity and inclusion. These programs implicitly raise awareness of and direct community effort to the better funded underrepresented groups. There is a concomitant multiplying effect from these federal programs; institutions that want to "do good" look to where the money is to support their efforts. For example, NSF encourages "broadening participation" in all solicited proposals. This is often achieved through successful faculty actively participating in the existing diversity and inclusion infrastructure on, or about, campus.

The second potential factor is the lack of critical mass in community for PWDs on campus. This is part of the "vicious cycle" (*1*). While undergraduate and graduate SWDs populate campus at levels approximate to black and Hispanic students, the upper level of postdocs and faculty are not available as role models and mentors. NSF suppresses demographic data on postdoctoral associates with disabilities, the pool from which faculty are trained, due to lack of numbers (*4*). Additionally, the population of truly successful students to act as peer role models may be lacking based on the attrition rates at each educational level.

STAYING ON THE RIDE: SUSTAINING CHANGE IN EDUCATION

Even if normative arguments fail, one might still believe that if there is evidence that something works, people will do it. In practice, this is a myth that undermines educators' ability to make change. Even with effective, evidence-based practices in hand, initiating change is complicated by human emotions, beliefs, desires, and politics. Beyond that is an additional challenge—once a change occurs, how can it be sustained? Individuals in organizational settings of all sorts may be willing to try something temporarily with the expectation that eventually, the interest will pass and operations will return back to the status quo. Or, an organization may pursue change with the fullest commitment and conviction, but the pulls of circumstances, politics, finance, and environmental contexts can thwart even the most sincere effort.

Educating is an endeavor that resides in challenging systems. These systems are subject to external scrutiny, financial demands, legal obligations, research-to-practice gaps, and ill-defined pathways for improvement. And yet, the primary question driving change has been, "What works?" not "How can change occur and last in complicated systems?" The good news is that the field of education knows a great deal, through research and accumulated expert knowledge, about what works. The challenge is that knowledge about how one facilitates the implementation, spread, and sustainability of those practices lags behind. If making change happen were as simple as telling people what worked, regular implementation of new and improved practices would be an ordinary part of organizational life. This is not yet common practice.

Another myth that has thwarted progress toward understanding how to implement and sustain new practices is the assumption that the answer to sustainability is simply finding more money. Individuals inclined toward developing and bringing about new practices often seek funding from external sources and the most skilled at that form of fundraising get it. This creates a dangerous assumption, namely that because money was needed to start an endeavor, it is all that is needed to continue. Indeed, money helps. But it is not an explanation for why people do and don't adopt practices. Money may be an incentive that entices someone to try something new, but other reasons influence their decisions to continue those practices, with or without a monetary incentive.

As funders and political leaders see their efforts implemented and all too quickly depart, in a time of limited resources, questions about sustaining change are becoming increasingly visible. In order to capitalize on this opportunity, it is essential to build on all that is already known about spreading and sustaining innovations. Theoretical frameworks have emerged from the fields of health, psychology, education, and others (*10–12*) that afford those newly entering this conversation with an exciting opportunity to build on a strong foundation, rather than reinvent ideas. Just as we want to ensure that our educational improvement efforts are implemented and endure, we need to turn to ourselves to take responsibility for using existing knowledge and improving it. Research on diffusing and sustaining innovations in education is not new (*13–16*), but it is relatively under-developed. It is true that an innovation needs to work in order to last. That, however, is not enough. Changing practices is about changing people, changing organizations, and changing culture.

What Does Sustainability Mean?

Before educational institutions can progress toward understanding how to sustain new practices, it is essential to be clear about what "sustainability" means. As with any endeavor seeking to build on and accumulate new knowledge, it is critical to use clear and precise language. In literature within education and other fields, sustainability is used interchangeably with many words including "institutionalization," "diffusion," "scale-up," "dissemination," and "maintenance" (*17–19*). *Maintenance* is a simple way to capture what many mean when they refer to sustainability. Generally, they simply mean the continuation of a reform, program, practice, or set of behaviors in their entirety for as long as possible and ideally, forever. The notion of *maintaining* an innovation works with certain boundaries, but not if there is an intention for the innovation to spread or endure over the long term.

When innovation goals turn to wanting to spread or "scale-up" the innovation; or endurance for more than five years (at a minimum) to 10 or 15 years or longer, sustainability as maintenance no longer works. For innovative, effective practices to spread and endure, they must adapt. It is the paradox of sustainability that in order to last, innovations must change.

This assertion begins to get at deeper questions of fidelity of implementation and how much adaptation is too much. While key to understanding sustainability, that work is beyond the scope of this piece. Suffice to say that research shows that in order to last, effective innovations must adapt to local contexts and conditions (*20, 21*). As long as those adaptations are "principled" (based on the principles underlying the innovation) and not "lethal" (departing from the underlying principles of the innovation), innovation integrity can be maintained.

It is ironic that sustainability isn't actually about things staying the same; sustainability has to do with change. Ultimately, as the contexts and conditions inevitably shift around educators, those educators need the frameworks, tools, and understandings that can help them decide what is core, and what is ineffective or obsolete. Program elements that once were useful or effective stop functioning as such due simply to the ongoing evolution of features of the program environment. Program elements that may have been necessary to get a program started, can become a burden as the program progresses.

At its core, the most important elements of an innovation are the program elements that contribute to desired outcomes and reflect the fundamental beliefs and values that support the most impactful strategies. In order to keep the essential core, one must first characterize this core and then remove the ineffective and obsolete. This is where systematic research, collaboration, communication, and accumulation of knowledge come in. Century and Levy (*22*) offer this definition of sustainability: "The ability to maintain core beliefs and values and use them to guide adaptations to changes and pressures over time." Ultimately, innovations are instantiations of core beliefs and values supported by research, experience, and expert opinion. Specific strategies, structures, and leaders can change; the core beliefs and values as operationalized in strategies that will accomplish desired outcomes are the essential core.

Change takes place in stages. At the beginning of an effort, it is worthwhile focusing on strategies that have demonstrated success and staying true to original designs. This helps communicate the approach, strategies, and goals to others and enables them to better understand what to do and when. After some time, however, needs for continuing the innovation being to shift. The typical goal for sustainability has been to keep the program going, as is, through a consistent, on-going source of money—to stay the same; to maintain. But the goals for educational innovation need to be more ambitious. The goal of an innovation is not to change *and then* stay the same. The goal is *continuous* growth and improvement. Innovations are about changing the status quo.

Alongside their peers without disabilities, persons with physical disabilities can pursue a variety of lab research tasks independently.

Sustainability is not about sustaining the *new* status quo, but rather about sustaining *change*.

Necessary Conditions for Change to Occur and Endure

Literature on organizational change and diffusion of innovations has identified many factors that affect the spread and endurance of change (*21, 23–25*). Generally speaking, these factors fall into four large categories: characteristics of the innovation; characteristics of the user; characteristics of the organization; and characteristics of the environment. Characteristics of the innovation pertain to the "thing" under discussion, i.e., the innovation or intervention. These qualities include flexibility, complexity, usability, feasibility, scope, and evidence of effectiveness. Characteristics of the user pertain to users at all levels of a system engaged in making a change and include qualities that are shaped by the innovation itself (e.g., self-efficacy and attitude) and those that are more general (e.g., resilience, innovativeness, "networked-ness") (*26*). Organizational qualities are often defined by the organizational climate or culture and pertain to communication systems, perceptions of the functionality of the organization, and beliefs about the capabilities of the organization. And finally, environmental characteristics pertain to the range of circumstances surrounding the organization including opinions of community members, political events, and even natural disasters.

All of these elements operate simultaneously, to varying degrees, at different times in the life of an innovation. Nobody can navigate them all with equal attention and effort. The savvy leader, however, will be aware of them, consider them strategically, and address those that present themselves at a particular time as the greatest barriers to progress. Change is a dynamic process for all participants—those who initiate the change and for those who enter the process as it progresses.

Literature in education, psychology, and health documents these specific characteristics well (*21, 23–26*). As educators seriously pursue efforts to assess conditions for change and measure the extent to which particular elements are affecting a change effort in progress, these existing efforts will be essential resources. Looking at what is already known can result in a shift in understanding for newcomers, leading them to change in surprising ways. Additionally, contexts and conditions that are expected to affect sustainability may do so in unexpected ways.

Financial resources (which would fall into either the organizational or environmental category, or both), for example, long thought to be the answer to sustainability, can sometimes create challenges. At the same time that funds support on-going activities, financial resources can create personal resentment within the organization. This can generate a rift in organizational collaboration and communication, ultimately sabotaging innovation longevity. An influx of financial resources that might come from a grant or specific budget allocation for startup can also create dependency. The presence of those resources, while necessary, can have the unintended consequence of supporting a "maintenance mentality"; a mindset that the effort will only endure with a continuing stream of level funding.

It is easy to become paralyzed by the complexity of these operational specifics. But fundamentally, they can be organized with a relatively simple conceptual heuristic based on capacity and will:

Capacity + Will = Change

When there is capacity and will, change will begin and continue. When one of these falters, change will stop. Capacity can be organized in to four categories: human capacity, organizational capacity, structural capacity, and financial capacity (*28*). Human capacity (like "characteristic of the user") pertains to the knowledge, skills, and expertise of the individuals involved. This is often the focus of change efforts based on the assumption that if individuals know how to do something, they will do it. There is no question that if they *don't* know how to do it they won't do it; but simply knowing how to do something doesn't mean people will choose to follow that path. Organizational capacity (like "characteristics of the organization") includes the aspects of an organization that comprise a culture of collaboration, shared understanding, and communication. Structural capacity refers to the elements in an organizational or external environment that concretely outline and support expectations such as policies, legislation, and accountability structures. Financial capacity is self-explanatory.

Dialogues about making change happen focus on capacities perhaps because they are very concrete. But the other essential piece of the equation is will (*28*), which is often overlooked. Will is complex. It includes extrinsic motivators such as compensation and recognition. But these motivators tend not to be as powerful as intrinsic motivators such as consistency with beliefs and values. Another way to describe will is in terms of an individual's desires. Ultimately, change comes down to individuals' single daily decisions and those decisions are shaped by the environment and capacities that those individuals and others around them embrace and develop. If educators want to maintain a change as status quo, they should find money. If they want to sustain change, they should build capacity and will.

PRACTICAL SUGGESTIONS FOR SWD PROGRAMS

A number of valuable programs and interventions have been developed aimed at improving the educational experience of SWDs in STEM fields. A basic literature search found a number of representative programs and successful interventions. Pedagogical and curricular initiatives for these students have been researched and implemented into the STEM classroom at a variety of grade levels (*29–32*). Efforts have been made to improve accessibility for SWDs in the classroom/laboratory in chemistry (*33, 34*) and computer sciences (*35, 36*), to name just two fields. A number of actions were taken to encourage more SWDs into STEM fields: workshops have been conducted to brainstorm ways to make careers more attainable (*37, 38*), an opportunity was developed for middle school students to be involved in hands-on outreach activities (*39*), and a transitional program for college-bound high school SWDs was established and evaluated for gender (*40*) and disability-type (*41*) preferences toward STEM fields.

Disability-specific interventions have also been implemented to target the unique needs of SWD groups. For example, activities designed for the needs of deaf and hard-of-hearing students have included an opportunity for high school students to conduct lab-based internships in chemistry (*42*), an inquiry-based intervention to teach general science (*43*), and a unique Associate's degree granting program where students are trained for employment as chemical technicians (*44*). Likewise, initiatives aimed at improving science education for blind and low-vision students have included a teacher training workshop (*45*) an outreach summer camp for students in computer sciences (*46*), and also a camp for students in chemistry (*47*). Many other interventions have been established to focus on students with a variety of physical, mental, and emotional disabilities and in a range of STEM disciplines.

These examples provide a sampling of efforts that have disseminated information about their activities and show the breadth of endeavors that have been undertaken. Though the multitude of past and current initiatives to improve STEM education for SWDs have considerable merit, discussion of their sustainability efforts are often brief or lacking altogether in the literature. Although it is possible that many projects may have had sustainability plans as part of their proposals and as part of evaluation criteria not publically reported, it seems likely that, except in rare cases, sustainability is not addressed in a concerted manner.

We suggest, therefore, that both program funding agencies and those soliciting such funding should explicitly address sustainability as it relates to characteristics of innovation, characteristics of the user, characteristics of the organization, and characteristics of the environment. Funding agencies might consider augmenting calls for proposals to solicit explicit planning on any or all aspects of these four items. Even without such formal calls, however, proposing investigators might consider adopting these as a sustainability paradigm to help focus arguments, and more importantly, actionable strategies to ensure long-term viability of programs for SWDs.

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Workshop Speakers, Attendee List, and Thank Yous

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Presentations on current policies of select federal agencies to increase the inclusion of persons with disabilities in STEM careers were given by Dr. Clifton Poodry, Director of the Division of Training, Workforce Development, and Diversity for the National Institute of General Medical Sciences (NIGMS); Kathleen Martinez, Assistant Secretary of Labor for Disability Employment Policy at the U.S. Department of Labor; and Dr. Karl Booksh, Professor of Chemistry at the University of Delaware and member of the National Science Foundation Committee on Equal Opportunity in Science and Engineering (CEOSE).

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[3]Panelist for "College Students with Disabilities in STEM: Expanding Opportunities by Enhancing Communication of Evidence-Based Information with Stakeholders"
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