

Accommodating Students with Disabilities in Science, Technology, Engineering, and Mathematics (STEM)

Findings from Research and Practice for Middle Grades through University Education

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CHAPTER 1

INTRODUCTION

Americans with disabilities have worked for many years to achieve integration and full participation within society. Realizing this goal has involved overcoming physical, economic, social, cultural, and legal barriers to full access and inclusion. This effort has been particularly pronounced in the area of education. Access to education for students with disabilities in the United States has been mandated by legislation such as the Individuals with Disabilities Education Act (IDEA), as well as IDEA's historical predecessor, the Education for All Handicapped Children Act. Other legislation, such as the Americans with Disabilities Act (ADA) and the Rehabilitation Act, has supported efforts to ensure that Americans with disabilities have access to a quality education through the provision of classroom accommodations.

In addition to legislative mandates, a number of programs set up by government agencies at all levels, as well as private and non-profit initiatives, have worked to further the goal of improving the education of students with disabilities in the United States. Most notable among these are the efforts of Research in Disabilities Education (RDE), a program within the Division

of Human Resource Development (HRD) of the Directorate for Education and Human Resources (EHR) of the National Science Foundation (NSF). Since its inception in 1994, RDE has supported myriad research projects to improve educational access and success among Americans with disabilities. This particular volume represents one of those outputs. It is indebted not only to the support of RDE but also to the work of scholars and practitioners, many of whom have received RDE support, who have pushed the field of disability education forward.

STEM EDUCATION AND DISABILITY

The NSF has placed a high priority on the cultivation of a diverse science, technology, engineering, and mathematics (STEM) workforce in the United States (NSF, 1996, 2000, 2004). This concern has been echoed by the National Science Board in its 2010 report, *Preparing the Next Generation of STEM Innovators*. This study presents two mutually reinforcing observations. First, the nation's long-term prosperity is dependent upon "talented and motivated individuals who will comprise the vanguard of scientific and technological innovation." Second, every student in the United States "deserves the opportunity to achieve his or her

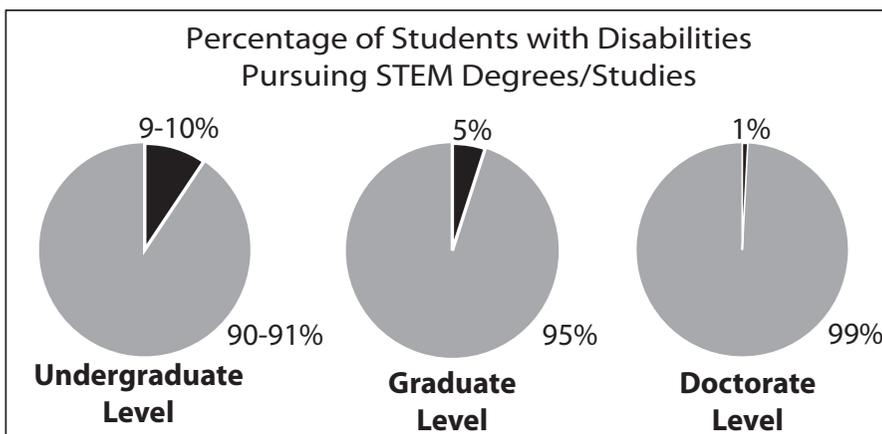
full potential” (National Science Board, 2010). In short, excellence and equity in STEM education are interrelated.

This goal can be realized only if underrepresented groups receive a larger proportion of the nation’s STEM degrees. Americans with disabilities historically have been excluded from postsecondary STEM education, as these students face significant barriers to access and inclusion in such programs. Research has demonstrated that when compared to peers without documented disabilities, students with disabilities enroll in and complete postsecondary education at only half the rate. Yet the problem is not limited to postsecondary education. Accommodating students in K-12 science and mathematics courses is often problematic, and many students with disabilities are not integrated within the general classroom and are relegated to learning in special education classrooms that do not prepare them for the rigors of university education in STEM fields.

Statistics demonstrate how representation of students with disabilities decreases longitudinally over the course of the STEM education process. According to IDEA, individuals with disabilities comprise about 13.7 percent of the school-aged population. However, the same demographic makes up only 11 percent of all students enrolled in undergraduate education and 9-10 percent of

students who are enrolled in STEM majors. This latter figure (See Figure 1.1) includes over 173,000 students in the United States, a significant proportion of the postsecondary population at risk of exclusion from STEM education.

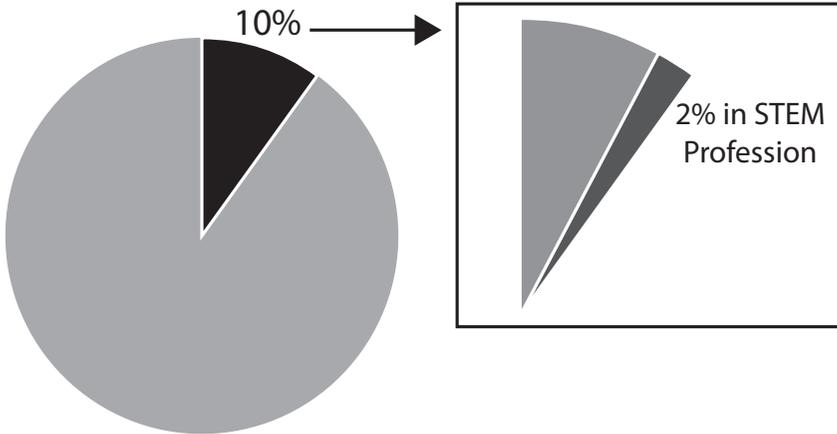
Figure 1.1



Participation beyond the undergraduate level is even lower, with only five percent of students with disabilities pursuing graduate degrees in STEM disciplines. In fact, only one percent of recipients of STEM doctorate recipients has had a disability. Returning to the aforementioned priority of cultivating a diverse STEM workforce, U.S. Census data has shown that people with disabilities constitute 10 percent of the nation's general workforce, but only two percent of its STEM professionals (See Figure 1.2).

Figure 1.2

10% of National Workforce has a disability, however only 2% are STEM Professionals



The problem is complex. First, teachers, instructors, and professors are frequently unable, unprepared, or otherwise ill-equipped to recognize and address the needs of students with disabilities. As a result, course content may be inaccessible, as many faculty fail to develop their courses in accordance with the principles for universal design for learning (UDL). Among instructors who are receptive to these needs, many may not be aware of strategies or technologies to help them accommodate students, or they may lack the necessary institutional support or resources to make accessible pedagogy a reality. In addition to the issue of accommodation, there is a second matter of

social inclusion. Research has demonstrated that students with disabilities, particularly learning disabilities, frequently encounter negative attitudes from faculty and peers (Johnson, 2006). By the time some of these students reach the college level, they are commonly discouraged from pursuing STEM degrees. When they do enroll in STEM courses, many are not fully included in more rigorous learning activities such as labs, thus diminishing their potential engagement and prospects for success.

Educators and policymakers long have emphasized the need to overcome disparities of race, ethnicity, gender, and socioeconomic status in realizing equality and diversity in STEM fields, and rightfully so. However, it remains vitally important that people with disabilities be considered, as well. This population remains underrepresented and frequently experiences outright exclusion. As such, there remains a pressing need for resources to ensure that STEM instruction is accessible and inclusive.

IMPETUS FOR THIS BOOK

Responding to this need, RDE has sponsored projects to address the accommodation of students in STEM. Its programs make resources available to increase the participation and achievement of people with disabilities in STEM education and

careers. The Demonstration, Enrichment, and Dissemination (RDE-DED) program track provides support to institutionalize accessible products and educational materials, enhance STEM learning experiences for students with disabilities, and disseminate information about effective products, pedagogical approaches, teaching practices, and research for broadening the participation of people with disabilities in STEM. Promising research efforts are developed under the Research initiatives (RDE-Research) program track via awards to contribute to the knowledge base by investigating disability related differences in secondary and post-secondary STEM learning and in the educational, social and pre-professional experiences that influence student interest, academic performance and retention in STEM degree programs, STEM degree completion, and student career choices. Research awards encourage assistive technology (AT) development, technology use in educational environments, and investigations of effective instructional methods and practices for people with disabilities in STEM. The Alliances for Persons with Disabilities in STEM Education (RDE-Alliances) program track provides support for comprehensive, multidisciplinary networks that increase the quality and quantity of students with disabilities completing high school, associate, baccalaureate and graduate degrees in STEM

who are well prepared for the science and engineering research, education and professional workforce.

This current volume is an extension of SciTrain: Science, Math, and Technology for All, an NSF-RDE sponsored project (Award No. 0622885) designed to train high school math and science teachers to become more effective instructors for students with disabilities. As part of its efforts, SciTrain developed a resource database with publications on science and math accommodations [<http://www.catea.gatech.edu/scitrain/kb/index.php>]. This book harnesses that database, but goes much further to survey the extant scholarly literature on the accommodation of STEM learners with disabilities from the middle grades through postsecondary education.

CONSIDERATION OF AUDIENCES

This book presents a survey of the literature on the accommodation of students with disabilities within STEM. While not necessarily an exhaustive compendium of that scholarship, it is intended to be a comprehensive overview of research conducted over the past decade for accommodating STEM learners in secondary and postsecondary education. Given the

fact that the literature in this area is quite voluminous, this book was developed with some specific audiences in mind.

This book focuses on the accommodation of STEM learners, with an emphasis on actual practices utilized by educators. Toward that end, we have chosen to emphasize the practitioner-oriented literature rather than theoretical scholarship. Furthermore, our decision to focus on research over the past decade, with some addition of selected “classics” from the literature, demonstrates an emphasis on showcasing recent promising practices and discussing current debates. One aim of this book is to develop a guide that can be utilized by educators, administrators, and other professionals to understand the array of accommodations options available. Our selection of recent literature reflects a focus on currency in understanding accommodations needs in today’s STEM classrooms and laboratories and the range of options currently available to educators and related professionals. As STEM education becomes increasingly reliant on cutting-edge instructional technologies, it remains imperative that pedagogy is not inaccessible to learners with disabilities. At the same time, it is important that technology-oriented solutions do not overshadow efficacious, process-based approaches for accommodating students with disabilities.

In addition to balancing “high-tech” and “low-tech” methods for accommodating students, we also wish to emphasize how accessible instruction can improve STEM education for all students, regardless of disability. Where possible, this book takes a universal design for learning (UDL) approach toward the development of accessible teaching. Certain accommodations are just that—accommodations—designed for overcoming a specific barrier encountered because of a student’s disability. However, the broader goal of accessible pedagogy frequently benefits both students with and without documented disabilities.

In addition to informing educational professionals about the accommodation of STEM learners with disabilities and the benefits of UDL approaches in education, this book also seeks to contribute to the research taking place in the field of disabilities education. In particular, we discuss practices that may be promising, but whose efficacy as reliable accommodations have yet to be determined. We also call attention to practice gaps, where work still needs to be done to address accommodations needs in STEM education for students with disabilities. While this volume is not intended primarily to inform the research agenda, we hope that our discussion of research and practice gaps may further those aims.

With concern for its intended audiences, this volume was developed with some specific boundaries in mind. First, our focus on currency means that the majority of literature surveyed comes from the last decade. Where scholarship from the 1990s may remain particularly relevant, selected works have been included, as have seminal “classics” in the field. In addition to an emphasis on recent research, this literature privileges the scholarly literature, much of which appears in relevant journals oriented toward STEM education, disabilities in education, and other practitioner-related issues.

Building upon the SciTrain project’s original concentration on accessible science and mathematics education in secondary education, this literature review extends that emphasis to consider the accessibility of STEM education for learners from the middle grades through postsecondary education (i.e. grades 6-16). Because instructional approaches for the elementary grades diverge greatly from middle school, high school, and university education, we have chosen not to consider them here. By contrast, accommodations in STEM education have a great deal in common over the course of these other grades. Where there may be differences in instructional approaches or accommodations, we

illuminate them, but the persistence and utility of many of these from middle grades to postsecondary education is striking.

CHAPTER OUTLINE

Chapter Two considers the accommodation of STEM learners according to their functional abilities and needs. Our use of “functional ability” is deliberate. While the more conventional concept of “disability” is more widely used when considering accommodation needs, our stated emphasis on functional ability derives, in part, from a focus on UDL principles. The notion of “design for all” means that all students, regardless of a documented disability, may benefit from accessible STEM instruction that takes into account their functional abilities.

In addition, many disabilities commonly experienced in the STEM classroom are complex in nature, implicating more than a single function such as memory or vision. For example, learning disabilities frequently involve some combination of sensory processing, memory, attention, and organizational difficulties involving more than one functional area. Nor are the experiences of students with disabilities uniform. For example, some students with attention-deficit/hyperactivity may have greater difficulty with inattentiveness, while others may struggle more with

hyperactivity. As such, there is a need to consider the individual experiences of STEM learners with disabilities.

Disability categories remain useful for organizing understandings of accommodations needs and options, and this literature review does not overlook them. However, where it is possible to do so, we strive to emphasize functional abilities based on the complex and individualized nature of disabilities, as well as the usefulness of such an approach for all learners in the STEM classroom.

Chapter Three examines the accommodation of learners according to specific STEM disciplines. While this chapter crosscuts the previous one and creates the potential for overlap, we have endeavored, as much as possible, to avoid such redundancies. But we recognize that instruction in mathematics, where learning emphasizes process-based approaches, differs significantly from more content-based subjects such as biology. Furthermore, teachers in the middle and high school grades and instructors at the college level tend to be oriented more toward a specific field of knowledge. So, where the previous chapter may provide information on accommodating a particular disability, this one complements that knowledge by addressing teachers and their specialties.

Finally, Chapter Four discusses some of the salient debates within the accommodation of learners in STEM. Of particular note is our discussion of the differences of philosophy that exist between UDL-based and accommodations-based approaches for accessible STEM instruction. In the end, we recognize that each plays an important role and neither may exist without the other. However, we conclude that UDL approaches, where feasible, may enhance STEM learning for all students while serving as accommodations. In addition, this chapter discusses some of the key practice and research gaps that persist in the accommodation of students with disabilities.

CHAPTER 2

DISABILITY AND THE ACCOMMODATION OF STEM LEARNERS

INTRODUCTION

This chapter reviews the literature on how STEM learners may be accommodated according to their functional abilities and needs. We purposely have chosen “functional ability” as the key organizing principle in place of the more established concept of “disability” for several reasons. First of all, this literature review highlights accommodations that adhere to universal design for learning (UDL, alternately known as universal design for instruction, or UDI) as part of inclusive education strategies (Burgstahler & Cory, 2008; Rose & Meyer, 2006; Rose, Meyer, & Hitchcock, 2005). These “design for all” principles can work to the benefit of all students in the STEM classroom or laboratory, while also fulfilling the role of accommodations for students with disabilities.

Second, our emphasis on “functional ability” better serves as an organizational tool because of the complex, wide-ranging nature of many disabilities. Blindness may be understood conventionally as a single sensory impairment affecting an

individual's visual abilities. Yet, other disabilities such as spina bifida may have implications for several functional categories, simultaneously involving mobility and dexterity impairments, as well as learning and cognitive disabilities. Other categories of disability may be experienced quite differently from person to person. For example, some students with attention deficit/hyperactivity disorder (ADHD) may struggle with inattentiveness more than hyperactivity, while others may find hyperactivity to be a greater challenge than inattentiveness. Moreover, learners with ADHD tend to have individualized experiences with the disorder that make blanket recommendations for accommodations or other supports difficult. With this focus on functional ability rather than traditional disability categories in mind, we have taken the approach of examining the complex and variable ways in which disability actually may be experienced in the STEM classroom. Through an emphasis on the intersection between STEM educational activities and the sensory, mobility, dexterity, and cognitive functions necessary for learning, we hope to provide our audiences with a practical, versatile resource.

At the same time, however, we recognize the usefulness of "disability" as an established concept. The scholarly and practitioner literature surveyed in this book generally discusses

accommodations in response to a specific disability need. Hence, one must consider established categories of disability when addressing the issue of accommodation in the STEM classroom and laboratory. However, the accommodation of an individual student with a documented disability should be complemented by universal design principles that can benefit all learners. We seek to provide a volume that will benefit the educator who needs to understand how best to accommodate a student with a hearing loss or spina bifida, for example. But we also endeavor, where possible, to illustrate UDL approaches that will lead to more accessible and inclusive instruction for all.

SENSORY FUNCTION

Hearing and vision are the only two categories of sensory function for which student statistics are readily available, but even within that constraint, it is clear that sensory disabilities are relatively common within the student population. Among postsecondary students reporting a disability, 32 percent report a sensory function limitation (Horn & Berktold, 1999). Conventional classroom instruction demands a high level of visual and auditory function across all fields and at all educational levels, but especially for secondary and postsecondary STEM education.

Tasks such as reading, note taking, listening to lectures, and producing written tests or papers have been studied intensively, especially in K-12 education, and accommodation techniques are fairly well established. But as students progress through high school and university education, the problems of basic access to visual and auditory instruction grow more complex as the intensity of information flow increases. Furthermore, STEM education combines traditional classroom activities with labs, fieldwork, and design studios, demanding even more of students' sensory functions. Whether it involves viewing bacteria under a microscope or detecting tonal differences in sound waves, STEM education frequently engages the senses, particularly vision and hearing.

For this reason, sensory impairments must be properly accommodated in order for students to be engaged fully as learners. While students with sensory impairments may rely upon accommodations to ensure their ability to learn, all students may benefit from pedagogy that is accessible and inclusive. In this section, we highlight the two main aspects of sensory function, vision and hearing, and discuss how learners with functional needs may be accommodated in the STEM classroom and laboratory. Where possible, we also suggest how all students can

benefit when course components such as lectures or PowerPoint presentations are designed and delivered with accessibility in mind.

Blindness and Vision Impairment

Vision function ranges across a broad spectrum. Some individuals may have “normal” 20/20 vision, while others may rely upon corrective lenses to improve their visual acuity. For others, visual function may range from impairment just beyond what is correctable with eyeglasses to total blindness. Collectively, about 16 percent of all postsecondary students report having a vision limitation (Horn & Berktold, 1999).

Low vision and blindness present numerous challenges to classroom learning, particularly in STEM fields where instruction relies heavily on graphically conveyed information, such as charts, graphs, diagrams, engineering drawings, photomicrographs, and 3-D simulations (Jones, Minogue, Oppewal, Cook, & Broadwell, 2006; Wu, Krajcik, & Soloway, 2001). Even students with low vision (See Figure 2.1) who may be able to access technical information when presented in textbooks or websites may find graphics difficult or impossible to access when presented on a classroom whiteboard or projector (Borland & James, 1999). Compounding

this problem is the possibility that low-vision students may not even seek accommodations for a variety of personal reasons, even though they may acknowledge privately that they need them (Richardson, 2009).

Example of what some students with low vision may experience while trying to see a classroom blackboard

Figure 2.1

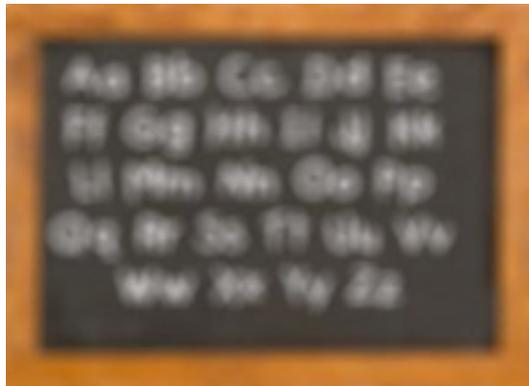


Photo credit: <http://www.uniteforsight.org/>

Other obstacles to accessible learning present themselves during lab classes and fieldwork. A number of researchers have emphasized the “hands-on” nature of STEM education and the problems it poses for students (and instructors) with disabilities. In this context, “hands-on” often means “eyes-on,” as a large proportion of laboratory-based science and technical

education depends heavily on visual observation. Few laboratory instruments were originally designed to utilize the hands, skin, ears, or nose to convey quantitative information. Rather, they depend on the observation of printed or embossed scales, changes in color, electronic numerical indicators, CRT displays, or other graphical means.

Modifications of Facilities and Labs

A number of accommodations for STEM learners with visual impairments have been discussed in the literature. Where practical, personal laboratory assistants may be used (Pence, Workman, & Riecke, 2003). Unfortunately, such assistants may diminish the laboratory experience for the student. Reliance on assistants also undermines principles of inclusivity in the STEM laboratory. Where possible, accommodations should permit students to participate as fully as possible in lab instruction.

An emerging school of thought in STEM education holds that laboratory science should be “multisensory” in order to be effective for all students, especially those with disabilities (Fraser & Maguvhe, 2008). The use of multiple means of presentation entails developing laboratory experiments and facilities to engage senses other than sight (Erwin, Perkins, Ayala, Fine, & Rubin, 2001). One

teaching tool, widely used for many years in medicine, chemistry, and other fields, is the large-scale model (such as an anatomical model). Physical models that incorporate sufficient tactile features are available, and they have been used in many STEM fields for the primary benefit of sighted students. For example, haptic models of the earth and moon allow students to feel geographic features such as mountains or craters, in addition to seeing them. Even models that rely partially on sight for their use, such as molecular models that use color for different elements, may be easily adapted so that students can utilize their sense of touch to discern different atoms. As pedagogical aids useful to students with vision impairments, such models also represent an example of a universally designed teaching tool (Wu, Krajcik, & Soloway, 2001). As the widening availability of high-quality, low-cost graphical materials and computer simulations threatens to displace their use, instructors should consider the advantages these low-tech pedagogical aids may still provide.

For more specific accommodations needs, a number of assistive technologies have been designed specifically for STEM laboratory education, such as modified instruments that feature an audio output in lieu of more commonly used visual outputs, such as a meter or graduated scale. Lunney (1995) described one

early adaptation, in which he assembled a relatively low-cost, PC-based workstation for students with visual impairments. The workstation included accessible sensors for light, temperature, pH, electrical resistance, voltage, and capacitance. More recently, Gupta and Singh (1998) developed a series of simple, accessible instruments, in which they built the prototypes and offered detailed construction plans. In a specific application, Singh (2008) published the details of a custom-built device to demonstrate viscosity without relying upon visual observation.

Laboratory instructors are routinely requested to employ other accommodations, ranging from Braille labels on equipment to special storage lockers. They also may rearrange the layout of lab areas for students with disabilities, enabling students with visual impairments to negotiate the lab space with greater ease. Supalo, Mallouk, Rankel, Amorosi, & Graybill (2008) described many of the recent published accounts of such accommodations for students with visual impairments, ranging from modified chemistry and physics lab equipment to tactile, 3D graphs (constructed by the instructor from drinking straws). While they may hold promise, the success of such solutions relies heavily on the personal motivation of individual instructors to meet the accessibility needs of their students. More importantly, the

STEM education literature has not yet agreed upon a standard design for an accessible lab in any major STEM field or at any educational level. The literature also provides few examples of accessible versions of advanced laboratory equipment used to teach STEM courses beyond the introductory level in colleges and universities (See Fraser & Maguvhe, 2008; Lunney, 1995). This fact means that neither a fully accessible lab nor other off-the-shelf accommodations may be available in all situations. While this gap certainly poses challenges for STEM instructors, it also represents an opportunity for faculty to develop their own solutions and adapt them to their particular instructional needs. Such efforts may be aided by the deployment of universally designed equipment and facilities that do not require active interventions to make them accessible.

Students who are blind frequently use the Nemeth Code for Braille Mathematics and Science Notation [Nemeth Code] to undertake mathematics. In their study on the preparation for and use of the Nemeth Code by teachers of blind and low-vision students, Rosenblum and Amato (2004) found that almost all teachers had taken at least one course in the Nemeth Code as part of their university preparation. Despite its prominence among learners who may already use standard literary Braille, the Nemeth

Code poses several concerns. First, students may not have access to textbooks in Braille, and when they do, discrepancies between the print and Braille versions are common. Second, instruction of students in the use of Nemeth Code takes considerably longer than time needed to instruct sighted students. Finally, teachers of blind and low-vision students often do not have the skills or knowledge necessary to prepare the materials or to teach Nemeth Code with confidence. While these teachers may have received some instruction, there is concern that far more instruction is necessary, not to mention experience. Furthermore, these teachers need more resources to assist them (Rosenblum & Amato, 2004).

Computer-based Accommodations

Owing to the increasing role played by computer-mediated instruction, students who are blind or have low vision are increasingly at risk for exclusion. Assistive technologies such as screen readers may help, but they are not a guarantee of accessibility, especially if the readers are unable to interpret the text. Fichten et al. (2009) provides the most comprehensive and current list of computer-related accommodations for students with vision impairments. Some of these accommodations are

related to classroom activities in general (note taking, reading, etc.), as those activities require a high level of visual function. For example, in-class PowerPoint presentations should be posted in advance of class meetings, or otherwise made available for students with visual impairments. Their availability allows students who use assistive technologies such as screen readers to interpret them during the class session. Also, the web-based course management systems that are widely adopted in universities are potentially useful for all students, but they must be designed or modified to allow access to screen readers, adjustment of font and image sizes, provision of captioned video, and should avoid text and/or background colors that render content inaccessible to people with color blindness. Standards for creating such electronic content are still evolving, but current guidelines are freely available to the instructors who teach, administrators who make decisions on these issues, and web designers who implement them (World Wide Web Consortium, 2010). In the end, the provision of technology is not enough. Modifications to instruction may be relatively minor and yet have the potential to increase vastly the accessibility of a STEM course; however, faculty training and awareness are essential to their success.

The list below provides examples of both special-purpose hardware and software accommodations developed specifically for students who are blind or have low vision, as well as a number of mainstream commercial products that have been successfully adopted by students as aids. That pattern of adoption, which does not seem to have been anticipated by the manufacturers, hints at the enormous potential of computer-based products to assist students (Goodman, Tiene, & Luft, 2002). A number of these accommodations are usable across a spectrum of disabilities and by non-disabled students, and are of special importance as universally designed technologies.

Computer-based accommodations for students who are blind or who have low vision

- Voice synthesizer software (for text-to-speech transcription)
- Screen readers
- Scanner hardware and software (used in combination with text-to-speech software)
- Text-based browsers and email clients (in combination with a screen reader)
- Specialized mathematics software
- Braille translation software, Braille printers, refreshable Braille

displays, Braille-to-speech conversion software

- Portable note taking devices with QWERTY keyboard and voice output
- Voice activated mouse
- Large monitor
- Software screen magnification
- Voice control of menus and toolbars
- Voice recognition dictation software
- Word processing software featuring word-completion, spelling checker, etc.
- “Mind mapping” software and other software aids to composition

(See Edyburn, 2000; Kapperman, Sticken & Heinze, 2002; Kapperman & Sticken, 2003; Kapperman, Sticken, Ohtake & Kanahori, 2003; Fichten et al., 2009; Fraser & Maguvhe, 2008; Suzuki et al., 2004)

Deafness and Hard of Hearing

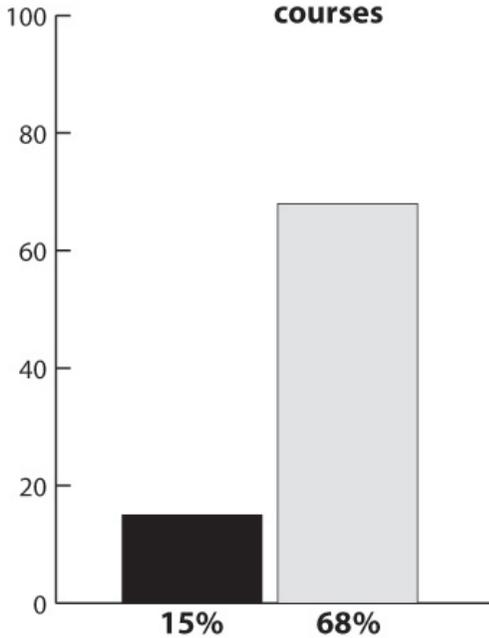
This section addresses hearing loss and their accommodation in STEM education by focusing on barriers faced by STEM students who are deaf or are hard of hearing. This section also outlines promising practices educators have established

to address these problems, as well as examining emerging and nontraditional pedagogical methods to aid in the instruction of learners with hearing loss. Such students are commonly encountered, as approximately 16 percent of postsecondary students with disabilities report being deaf or hard of hearing (Horn & Berktold, 1999).

Historically, students with auditory limitations have lagged behind non-disabled peers in STEM education. One study indicated that deaf and hard of hearing students in the senior year of high school performed at a sixth-grade level on the mathematics computation portion of the Stanford Achievement Test and around fifth-grade level on the problem solving portion (Traxler, 2000; Pagliaro & Kritzer, 2005). A similar study by Dowaliby, Caccamise, Marschark, Albertini, & Lang (2000) found that nearly 80 percent of rising freshman in associate's degree programs scored below the 50th percentile on the ACT Mathematics Subtest. The same study (See Figure 2.2) revealed that approximately half of incoming university freshman require remedial mathematics courses as a part of their degree program, with only 15 percent of deaf or hard of hearing students achieving or exceeding their recommended performance level (Blatto-Vallee et al., 2007). Qi and Mitchell (2011), in a study of decades of

Figure 2.2

Percentage of deaf or hard of hearing students exceeding their recommended performance level in freshman remedial mathematics courses



15% of students who are deaf or hard of hearing exceeded their recommended performance level and 68% exceeded their recommended performance level after they received appropriate interventions.

achievement scores, confirm that achievement gaps between deaf and hard of hearing students and their hearing peers remain large. But with appropriate intervention, 68 percent of students exceeded their expected performance on the Nelson

Age Appropriate Achievement Test, despite possessing somewhat slower reaction times than their hearing counterparts (Blatto-Vallee et al., 2007).

Student Issues

Longstanding academic underperformance among students with hearing loss may be attributed partially to the fact that much of STEM education takes place within the general classroom. Frequently, middle school and secondary science and mathematics teachers have not received sufficient training to accommodate these students with disabilities, while the special education teachers capable of understanding and addressing a wide variety of functional needs do not teach general and advanced science and mathematics courses at these levels. For this reason, collaborative efforts between these two educators are crucial in fostering inclusive education for deaf or hard of hearing students. Beyond K-12 education, there remains a need to ensure that university instructors are attuned to the functional abilities of their students, including those with deafness or who are hard of hearing. At the postsecondary level, UDL approaches to pedagogy become all the more important.

A robust body of literature exists studying the manner in which learners with hearing loss process information, with a focus on addressing pedagogical needs in STEM courses. Lang and Pagliaro (2007) conducted a study to determine how factors of familiarity, imagery, concreteness, and signability impacted the abilities of students with auditory limitations to recall geometry terminology in both the short term (i.e. working memory) and long term (i.e. semantic memory). The authors concluded that “deaf and hearing individuals may encode information in qualitatively different ways.” As other authors have noted:

Whether we are referring to knowledge of mathematics such as its conventions or tools and logic and reasoning, often remembered and used for a short while or lasting months or years and accessed for a wider variety of purposes, understanding the role of long term memory and any similarities and differences between deaf and hearing students is essential to good instruction. (Lang & Pagliaro, 2007; Marschark, Lang, & Albertini, 2002)

Bearing in mind this relationship between hearing and memory, especially in terms of one’s ability to retain knowledge, it may come as little surprise that deaf students consider content knowledge the most important attribute of an educator (Lang,

McKee, & Conner, 1993, as cited in Lang and Pagliaro, 2007). While the extant literature focuses primarily on mathematics, it remains to be shown whether these same processes are at work when students with hearing loss study other STEM fields with both abstract theory and practical applications.

Ultimately, this study finds imagery (i.e. the ability of the “mind’s eye” to depict or render an image or concept) and familiarity, in terms of ability to retain and recall content, to be the most important factors in students’ ability to remember geometric terminology. Regarding signability, the studies discussed above corroborate the findings of classic research (Bonvillian, Orlansky, & Novack, 1983) that students found concepts represented by a single sign much easier to recall than those which require compound signs or fingerspelling (Lang & Pagliaro, 2007). Hence, the authors follow this established scholarship by recommending the use of visual aids to enhance imagery and familiarity more thoroughly within the STEM curriculum, including mathematics courses such as geometry, especially when teaching unfamiliar or abstract concepts. While such accommodations might aid learners with hearing loss, visual aids simultaneously serve as universally designed approaches that can benefit a wider set of students, including those without disabilities. More specifically, this study

recommends that special attention and visual reiteration be paid to terms represented by multiple signs or that require fingerspelling (Lang & Pagliaro, 2007).

A similar study by Blatto-Vallee et al. (2007) examines the visual-spatial representation of math problems by students who are deaf or hard of hearing. This comparative case study builds on research by Hegarty, Shah, and Miyake (1999), in which a group of Irish middle-school students took a series of standardized tests. Responses were categorized to determine whether students relied on the schematic relationship between elements of the problems to determine the answer or if they merely pictorially represented relevant components of each problem. Students who noted schematic relationships far outperformed their pictorial counterparts. Blatto-Valle and colleagues replicated this study with deaf and hard of hearing students from middle school and high school, as well as associate's and bachelor's degree programs, finding deaf students to be far more likely to use pictorial over schematic methods to represent a given problem. As a result, these students were consistently outperformed by their hearing counterparts in most cases. More generally, students who used pictorial representations to solve math problems performed significantly lower than those who used schematic

representations, regardless of their hearing limitation. Ultimately, this study determined that deaf and hard of hearing students may focus on irrelevant aspects, especially in assignments with word problems. Hence, accommodations should be aimed at streamlining material so that students are able to focus on the relevant details needed for problem solving.

Pedagogical Issues

The second major contributing factor to under-performance among students with hearing loss in STEM classrooms is the lack of qualified teachers who understand their functional abilities and can address their accommodation needs, while simultaneously possessing the teaching knowledge and credentials for advanced STEM coursework. Kelly, Lang, and Pagliaro (2003) found that 76 percent of mainstream math classes were taught by certified teachers, whereas instructors in only 9 percent of self-contained schools and 39 percent of residential/center schools could boast those same credentials. Lang and Pagliaro discovered that despite a significant difference among deaf and hearing teachers with regard to geometry word recall, no significant difference existed among certified math teachers and their uncertified counterparts, regardless of the auditory

ability of their students. These findings reinforce the theory that educational disparities between hearing and deaf and hard of hearing students in STEM coursework owe more to undertrained instructors than the students themselves. To rectify this, the authors recommend that workshops be implemented to teach appropriate image-based and iterative strategies necessary for effective instruction of these students (Lang & Pagliaro, 2007).

Looking more specifically at the topic of advanced mathematics instruction, Pagliaro and Kritzer (2005) conducted a study to discern whether discrete mathematics methods were actively used in deaf and hard of hearing classrooms. The field of discrete mathematics involves the practical application of many mathematical concepts. Despite the fact that the 1995 National Action Plan for Mathematics Education Reform for the Deaf included a clause discussing the use of discrete mathematics concepts, educators of deaf and hard of hearing students were still relying on a rational-mathematics based curriculum a decade later (Dietz, 1995). Scholars found that this lack of pedagogical innovation in teaching discrete mathematics was owed not to a lack of knowledge by the teacher, but rather, the perception that the concepts were prohibitively difficult. In order to address this longstanding issue, researchers in the practitioner-driven

literature have stressed a need for teachers to have more confidence in the abilities of their students (Pagliaro & Kritzer, 2005).

Solutions

In an attempt to address some of these accessibility challenges, Kelly, Lang, Mousley, and Davis (2003) developed a software application aimed at both deaf and hard of hearing students and students with learning disorders to improve analytical and problem-solving skills, particularly with regard to word problems. Kelly's stated objective was to ameliorate linguistic or reading comprehension barriers faced by these students (Kelly et al., 2003; Ansell & Pagliaro, 2006; Barnham & Bishop, 1991). Singled out as particularly troublesome for these students were "language structures that include conditionals (if, when), comparatives (greater than, the most), negatives (not, without), inferentials (should, could, because, since), low information pronouns (it, something) and lengthy passages" (Kelly et al., 2003; Rudner, 1978). More recently, Kidd and Lamb (1993) discovered additional complexities impeding word problem comprehension, including the fact that many words have different meanings in a mathematical context than they would otherwise.

Furthermore, alternative and varied ways of articulating an expression, concept, or symbol have been implicated in the challenges that deaf and hard of hearing students face in the comprehension of word problems (Kelly et al., 2003). Kelly et al.'s (2003) Problem Solve was designed to address these issues, especially among high school and university learners. The software package represented one example of computer-mediated approaches to familiarize users with the vocabulary and word structure commonly found in high school and collegiate word problems, as well as provide supplemental instruction for each concept (Kelly et al., 2003).

In the area of science education, Seal, Wynne, and MacDonald (2002) have observed that the shortage of qualified science instructors for deaf students is more severe than shortages in mainstream schools. As a result, many higher-level science courses have not been made available to deaf students. Attempting to alleviate this problem and address these issues of exclusion, Seal, Wynne, and MacDonald (2002) brought together undergraduates from Gallaudet University, instructors from Virginia School for the Deaf and Model Secondary School, a group of sign language interpreters in training, and professional interpreters in a biochemistry classroom and lab setting for a pilot

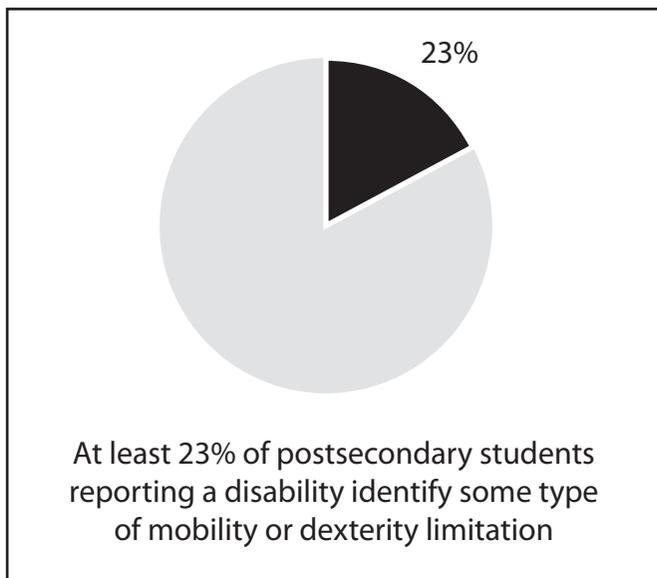
program. The collaboration was intended to educate the students and teachers in biochemical concepts and lab procedures, while instructing the next generation of sign language interpreters in the highly technical concepts so they could provide the most accurate and insightful explanation possible. Teachers were instructed in the best methods for educating students who are deaf or hard of hearing. One approach addressed a method to structure teaching to allow a deaf student to focus simultaneously on his or her interpreter and in-class demonstrations. Another promising practice involved review of the day's lessons to ensure that the interpreter understood the concepts being discussed adequately. This program provides one example of an intervention to bridge the established gap between advanced STEM instruction and pedagogy that is cognizant of the functional capacity of and accommodations needs for students who are deaf or hard of hearing.

In a somewhat less conventional approach, Chen (2005) advocates the use of origami to instruct hard of hearing students in geometric concepts, particularly those "math concepts inherent in origami that include spatial visualization, intersecting planes, area and volume, mirror images, and...symmetry" (Chen, 2005, p. 263) This technique takes advantage of the fact that hard of

hearing students rely on visual and tactile learning techniques. Ultimately, this method strongly advocates the addition of origami in math classes for these students (Chen, 2005). While this approach addresses elementary geometrical and spatial-thinking skills, it also anticipates the possibility of adapting similar techniques in secondary and postsecondary STEM education (Roald & Mikalsen, 2001).

MOBILITY FUNCTION

Figure 2.3



When considering mobility function and the accommodation of associated impairments within STEM education, it is important to remember that a wide range of conditions and diagnoses are involved. At least 23 percent (See Figure 2.3) of postsecondary students reporting some type of disability identify it as a mobility or dexterity limitation, and the proportion climbs higher when one considers temporary impairments such as injuries or broken limbs (Horn & Berktold, 1999). Even when considering the same diagnosis, mobility impairment involves a continuum of functional abilities. People with mobility limitations include people who cannot walk far due to fatigue and pain, such as a student undergoing chemotherapy. Some students can walk but do so slowly and with poor balance, while others use ambulation aids. Finally, manual and power wheelchairs may be used by individuals unable to walk or stand, whether for long periods of time or at all.

The continuum of mobility impairments may also be found within a single disability. Among people with cerebral palsy, some may have a slightly unsteady gait, while others may require the use of a motorized wheelchair. Further complicating matters, mobility impairments such as muscular dystrophy are degenerative, requiring constant reevaluation and adaptation

of accommodation approaches. Hence, evaluations for each student must take individual functional ability into account, and accommodations must be determined accordingly.

For teachers in STEM, effective accommodations rely upon instructor awareness about the specific students in their classrooms and their needs, combined with knowledge about the most effective accommodations frequently provided for students with mobility impairments. Despite the range of possibilities, it is possible to provide some generalized recommendations. While such general-purpose accommodations may not be exclusive to STEM classrooms, they should be considered as part of any strategy to accommodate students with mobility impairments.

In the first place, it is necessary to ensure students can enter and exit facilities easily and safely, as well as use them in the appropriate manner. The ADA Accessibility Guidelines for Buildings and Facilities (ADAAG) provide important guidance for issues such as parking, entrance, egress, maneuvering through school buildings, and general space and mobility considerations (U.S. Access Board, 2002). More specific ADAAG guidelines also exist for building elements intended for use by children (<http://www.access-board.gov/adaag/kids/final.htm>) (U.S. Access Board, 1998).

Classroom accommodations must take into account maneuverability, but also a number of positioning, communication, and social factors that make learning easier for students in the classroom setting (Stefanich, 2007b). A typical listing includes (Stefanich, 2007a):

- Provide classroom and laboratory aisles wide enough for a wheelchair to maneuver, a minimum of one meter in width;
- Provide open-backed, wheelchair-accessible desks that allow students to position themselves easily at their workspace;
- Allow workspace options; some students, particularly those who use motorized wheelchairs or who have accompanying dexterity impairments, prefer to work from trays mounted on their chairs;
- Adapt student desks and workstations to permit comfort and minimum physical effort;
- Provide graphs, charts, posters, etc., at an appropriate height and angle to be viewed by students using wheeled mobility;
- Examine trafficking needs of students and arrange room space accordingly;
- Review work areas for appropriate height and positioning for access, including wheel and leg room for wheeled mobility access;

- Be aware of social impact of mobility issues, and provide means for the student to interact freely with the class at large;
- Be aware of student needs for physical assistance and provide as necessary but guard against unnecessary intervention that will “single out” the student.

While no special standards for establishing accessible laboratory facilities exists, Roy (2008) offers some similar recommendations for ensuring the accommodation of students with mobility impairments in laboratory settings. These guidelines, which are based upon ADA and the Uniform Federal Accessibility Standards (UFAS), attempt to balance accessibility with safety concerns. Student safety should always be a consideration when making accommodations.

Laboratory Workstations:

- Controls for fixtures (electrical receptacles, gas jets, water faucets, sinks, and apparatus rod sockets) should be easy to access and use. They should require a maximum of 2.3 kg (5 lbs.) of force to operate.
- Also, fixture controls should require only a loose grip for operation instead of pinching the fingers or twisting the wrist. Where possible, single-action lever controls should be utilized rather than knob-type controls.

- At least one workstation should accommodate students with mobility impairments. More practically, dimensions for access should include a maximum height of 86 cm (34 in.) from the floor to the surface. To ensure knee space, the user opening should be 69 cm high x 76 cm wide x 48 cm deep (27 in. x 30 in. x 19 in.).
- To ensure wheelchair access to and from the workplace, clear floor space that is 76 cm wide and 122 cm long (30 x 48 in.) is necessary for the front wheelchair approach. Also, be sure that adequate space is provided throughout the rest of the laboratory to reach the station.
- Workstations should be located away from physical barriers and provide visual accessibility for instruction and demonstration. If needed, mirrors and electronic cameras may be utilized to maximize visual access.

Laboratory Sinks:

- ADAAG specify that sink depths in the laboratory should be no more than 16.5 cm (6.5 in.) to allow a wheelchair to fit under it. Also, knee space that measures at least 69 cm high x 76 cm wide x 48 cm deep (27 in. x 30 in. x 19 in.) is necessary. Finally, the counter or sink rim should be mounted no more than 86 cm (34 in.) from the floor.

- Sink faucets should have easy access and lever-operated controls rather than traditional knobs. Alternatives such as push-type, touch-type, or electronically operated controls are also acceptable.
- Clear floor space 76 cm wide and 122 cm long (30 in. x 48 in.) is required for laboratory sinks.
- To ensure safety, exposed hot water and drain pipes should be insulated or otherwise placed to avoid student contact with them. Also, there should be no abrasive or sharp surfaces under the sink.

Fume Hoods:

- Fume-hood decks should conform to the same height for knee space and floor space specifications for workstations and laboratory sinks. Decks should be no more than 86 cm (34 in.) from the finished floor, and knee space dimensions should be 69 cm x 76 cm x 48 cm (27 in. x 30 in. x 19 in.).
- Further, easily operable controls should be no more than 122 cm (48 in.) high, especially for new construction. Existing fume hoods with controls that are no more than 137 cm (54 in.) are generally considered acceptable.

Safety Eyewashes and Showers:

- The safety-eyewash station bowl and pull-handle shower

should be accessible to students with mobility impairments.

The eyewash bowl should be lowered, if necessary, so that the maximum height of the water-discharge outlets is 91 cm (36 in.) from the floor.

- New showers should have a pull handle no more than 122 cm (48 in.) above the floor, as well as be able to accommodate a wheelchair side approach. Existing showers where the handle is within 137 cm (54 in.) of the floor are considered acceptable.
- Showers require clear floor space of 76 x 122 cm. (30 x 48 in.)
- Flexible-hose showers installed in laboratory stations are not permitted by the Occupational Safety and Health Administration (OSHA) as the sole means for providing this safety feature.

Other Access Issues:

- Cabinets, bookcases, furniture, and equipment with sharp corners can pose a potential hazard. Storage cabinets on rollers or other alternative storage units may be useful in addressing this issue.
- Adaptations for specific laboratory equipment are often available for students with mobility impairments. Examples include extended eyepieces for microscope viewing for wheelchair users and beakers with handles to enable easier

access and use.

- Teachers and laboratory instructors should contact the building administrator with specific concerns about accommodations and safety. School or university administrations are usually required by the ADA to provide alternatives, such as portable units, to address any other issues of accessibility (Roy, 2008, pp.12-13).

Subject-specific Accommodation

It is imperative that science labs be accessible for students with limited mobility function. Experiments and demonstrations should be performed on an adjustable table that enables wheelchair users to see and access all materials. Similarly, laboratory sinks should be at appropriate heights, and available from three sides for those who have mobility/dexterity restrictions on one side. Ample space should be provided under lab tables and sinks for wheelchair users. It may be necessary to lower shelves and storage units to lapboard height, or provide moveable Lazy Susans or cabinets on casters (Stefanich, 2007a). Teachers should take care with dangerous or delicate equipment where students are forced to use exceptional reach, so they should seek to provide sturdy, safe substitutes (electric versus flame burners,

for example) when reach may be an issue. All operating knobs and controls for equipment should be easily accessible for students at lapboard height, where possible. Despite all accommodations, it may be necessary in some cases to provide manual assistant to help compensate for any issues of inaccessibility that may arise. In some cases, this assistant may be a fellow student laboratory or class partner (Stefanich, 2007a), and this can often be accomplished through standard lab partner routines, alleviating the stigma of “special” considerations for the student.

In many scientific classrooms, such as earth and environmental sciences, fieldwork and excursions into the environments and sites under study frequently complement classroom instruction. Hall, Healey, & Harrison (2002) discuss the ways in which students with disabilities can be accommodated and included in a fieldwork setting. Students with mobility impairments traditionally often face a difficult, if not impossible, task of negotiating the demanding terrains that characterize this kind of experience. For example, wheelchair users may find it difficult to navigate a rocky area. Yet Hall et al. emphasize that despite issues of access, wheelchair users are just as likely to “excel in describing the friability of soil, or the effort required to navigate a gradient” (p. 221). To accommodate these students, Hall et al.

chose a less strenuous path for the fieldwork experience. In a nod to universal design, it was offered not only to students with mobility impairments, but also to anyone who preferred a gentler terrain, even if it meant missing a few landmarks to provide an authentic, accurate field study experience. In some instances, a dedicated helper may accompany students into the field to help complete their task; however, emphasis should be placed on creating an inclusive experience, as students with mobility limitations may feel awkward and out-of-place in such a setting (Desforges, 1999). Again, an in-class lab partner may be used to alleviate the need for perceived “special” accommodations (Stefanich, 2007a). In addition, students with multiple disabilities may face other challenges beyond access that require instructors to determine individual solutions to provide accessible and inclusive fieldwork experiences (Hall et al.).

Fieldwork for students with mobility issues often requires extensive planning in advance in order to accommodate different transportation, parking, and ingress needs, as well as ensuring accessibility of destinations (Stefanich, 2007a). Event coordinators should contact destinations in advance to ascertain if temporary accommodations must be made. These may require moving obstacles or providing temporary ramps, or they may

be as simple as changing the height of displays for students using wheeled mobility. In extreme cases, it may be necessary to arrange in advance for alternate educational experiences where accessible routes are not available, for example, in some older museums, laboratory tours, observatories, and other typical STEM destinations.

Condition-specific Accommodation

A number of conditions that include mobility impairment often involve accompanying dexterity, sensory, cognitive, or learning disabilities. Hence, STEM educators are advised to treat the student comprehensively instead of on a condition-by-condition basis. Therefore, this section outlines some common multiple disability disorders and the best prescriptions for accommodating them in a STEM classroom.

Students with Duchenne muscular dystrophy (MD) for example, have a degenerative condition that requires constant evaluation of both the student's educational abilities and their needs as this particular condition progresses at an individual rate. One of many forms of MD, Duchenne MD refers to a genetic, hereditary muscle disease that cause progressive muscle weakening over time. Defects in muscle proteins eventually lead

to the death of muscle cells and tissue. Hoogerwaard et al. (1999) report a wide range of varying symptoms requiring frequent reassessment, including:

- Progressive muscular wasting (weakness)
- Poor balance
- Frequent falls
- Walking difficulty
- Waddling gait
- Calf pain
- Limited range of movement
- Muscle contractions
- Respiratory difficulty
- Drooping eyelids (ptosis)

As the symptoms impact various functional abilities and may change often in severity, teachers need to continue assessment throughout the educational journey. Other conditions that may impact mobility have their own list of likely limitations, including strain injuries (often temporary movement and range of motion problems), muscle damage (limitations of motion due to pain) and the effects of systemic conditions that impair joints, such as lupus.

In a STEM classroom, adoption and success of prescribed accommodations are also dependent upon the willingness of

the student. A study by Heller, Mezei, & Avant (2008) on students with Duchenne MD found that although students were willing to utilize assistive technology for other courses, they refused it for math classes, preferring to complete assignments manually. However, with the reduced range of motion and increased fatigue associated with mobility impairments, students frequently complete shorter assignments, often foregoing the ancillary assignments such as chemistry or biology labs.

The literature on UD approaches for accommodating students with mobility impairments in STEM education is rather scant. Moreover, the literature tends to focus on wheelchair users, but these students' needs are distinct from students using crutches or a student with poor balance. To rectify these concerns, the more robust literature on UD for workplace accommodations may be applicable. In their review of this literature, Zolna, Sanford, Sabata, & Goldwaithe (2007) noted that modifications to the physical environment constituted one of the primary means of accommodating individuals with mobility impairments. These ideas might be manifested within education as specially made desks or chairs to meet individual students' needs. However, the acquisition of adjustable desks and other furniture may help students with a range of needs. Moreover, attention to better

lighting, clear travel paths, ample maneuvering room, and no-step entrances may benefit all students. Classrooms and laboratories adhering to these general principles will be more accessible for all individuals, regardless of specific disabilities or accommodations needs.

DEXTERITY FUNCTION

Dexterity impairments refer to disabilities that may impair use of hands, which may range from fine motor skills to digit-specific issues (i.e. missing fingers or, alternately, polydactyly) to the complete inability to use the hands. In the context of the STEM student population, dexterity impairments usually refer to limitations in the fine movement or coordination of the hands in order to take lecture notes, operate a keyboard and mouse, or manipulate laboratory equipment. Such impairments may also involve upper-body weakness or physical endurance issues that affect the ability to perform those same tasks. While no statistics are available that focus on secondary and postsecondary students, a 2003 study by Microsoft Corporation estimated that the incidence of dexterity limitations among working-age computer users was as high as 25 percent (Microsoft, 2003). Functional limitations affecting the hands in the student population may be

even more common when temporary disabilities such as sports injuries are taken into consideration, suggesting the importance of this issue for many students and their teachers.

As with other disabilities, enrollment in STEM courses by students with dexterity limitations is lower than would be expected, apparently due in part to those students being discouraged from pursuing science as far back in their careers as their primary education, and resulting in students who gravitate to other majors or simply lack the qualifications to study STEM topics by the time they reach the university level.

Only a small body of recent scholarly and practitioner literature specifically addresses accommodations for dexterity issues, particularly technologically advanced accommodations, and most of that available literature focuses on therapy and rehabilitation rather than mainstream classroom integration. In addition, dexterity is usually treated as a subcategory of mobility, focusing on generalized motor impairments that also affect hand movement and coordination under the broad category of “orthopedic” disability (Blumenkopf, Swanson & Larson, 1981, pp. 216-217; Tombaugh, 1984, pp. 122-123). While limitations in mobility and dexterity may be medically related and often do

coexist, there are great differences between physical mobility and manual dexterity.

Dexterity impairments take on added significance in STEM courses, where manual activities such as laboratory experiments, design studios, and fieldwork are more common than in other fields. Causes of dexterity impairments vary widely, including congenital conditions (cerebral palsy or missing limbs due to birth defects), amputation, heart or pulmonary disease, carpal tunnel syndrome, and sports injuries. Even left-handedness, which ordinarily is not considered a dexterity limitation, may become one if equipment or facilities are not usable by left-handed people (Goodman et al., 2002, p. 82; Neely, 2007, pp. 1698-1699; Heller et al., 2008; Burgstahler & Bellman, 2009). The heavy reliance on hands-on laboratory instruction and/or fieldwork discourages full participation by students with dexterity limitations. These students, already at a disadvantage in taking notes or filling out tests in the classroom portions of STEM classes, are further challenged by the demands of adjusting a microscope, handling chemicals, or dissecting specimens (Bradley, Healey, & Fuller 2004, p. 464).

Accessibility in STEM classrooms for people with dexterity limitations tends to fall into three categories: 1) case-by-case,

largely non-technical accommodations, 2) modifications of the specialized equipment and facilities to allow full access, and 3) the use of add-on technologies to circumvent the difficulties posed by equipment or facilities. Ideally, if facilities and equipment incorporate universal design principles, they may be accessible to most students with disabilities, but that is rarely the case in STEM education.

The first category of accommodation is the simplest and involves non-technical accommodations determined on a case-by-case basis. Because of the wide range of severity in dexterity limitations (and many other disabilities), students with mild disabilities simply may require more time to finish written assignments or laboratory experiments. Other than the allowance of this extra time, such accommodations do not necessitate any changes to pedagogy or the classroom (Miner, Nieman, Swanson & Woods, 2001; Stefanich, 2007a, p. 20; Webb, Patterson, Syverud & Seabrooks-Blackmore, 2008). For students with more severe impairments, suggestions for accommodation in science classrooms include the employment of note takers for lecture classes or the use of a team learning approach that allows the student with dexterity limitations to take responsibilities other than those that rely heavily on dexterity skills (Stefanich, 2007a, p.

154, 248). At the university level, disability experts are apparently not commonly employed for this work, but hired workers (often work-study students) or volunteers from the classroom have been utilized for this purpose. So, for example, students unable to handle laboratory test tubes or other equipment with sufficient precision may watch as another person handles the equipment for them (Flick-Hruska & Gretchen, 1992, p. 19, 37-38; Miner et al., 2001, p. 67; Webb et al., 2008, p. 199). While they may be relatively easy to implement, these prescribed accommodations may undermine the full participation of STEM learners with disabilities. They have the unfortunate effect of separating the student, partly or wholly, from the intended laboratory experience of personally engaging in science. If laboratory work and related learning activities must be personally experienced for authentic STEM learning to occur, the provision of proxies such as personal assistants or helpers may represent an unacceptable solution.

The second category of accommodation is the modification of conventional facility or equipment designs to make them more accessible. Accessibility in chemistry and biology labs, for example, may include providing or adapting existing faucets, gas valves, and the like with paddle-type handles that are easier to manipulate than smaller, more traditional cross-shaped

handles. For students whose dexterity impairments entail the inability to hold lab glassware, for example, tongs (available in both left- and right-handed versions) are available. Equipment that is not specifically designed as an accommodation is also widely used, such as potholders for handling hot objects (Norman, Caseau, & Stefanich, 1998, p. 10; Miner et al., 2001; Neely, 2007, p. 1697). Handling of small amounts of dry chemicals can be accomplished without spillage by using spoons with sliding covers (McDaniel, Wolfe, Mahaffy, & Teggin, 1994; Miner et al., 2001, p. 68; Stefanich, 2007a, p. 231, 248). One study on dexterity accommodations in a basic electronics lab has suggested substituting larger electronic components for circuit construction and using connecting wires with large, easily manipulated “alligator” clips on the ends (Stefanich, 2007a, p.276). These solutions demonstrate that accessibility solutions for students with disabilities need not rely upon specialized, expensive AT. Rather, they may be accomplished through the adaptation of existing tools that are more commonly available at less expense.

An important broad category of accommodation involves computing and telecommunication hardware. Notably for students with dexterity limitations, this includes the use of

commercially available alternatives to mainstream computer input devices such as the standard keyboard and mouse.

Magnetic Control: Tongue Drive System at Georgia Tech

Figure 2.4

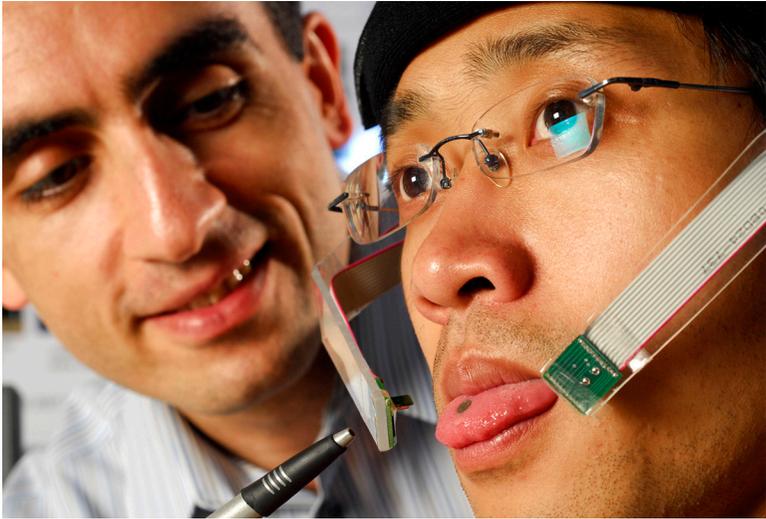


Photo credit: Georgia Institute of Technology

Larger, easier-to-manipulate computer mice have been commercially available for a number of years, including mice that may be operated with the feet. General computer input devices that substitute for a conventional mouse and keyboard combination include other AT such as tongue-driven technologies (See Figure 2.4), eye-tracking systems, and direct brain control (Moore, 2003; Fichten, et al. 2009; Wald, Draffan, & Seale, 2009).

For the many STEM courses or labs that require use of a calculator, accommodations such as calculators with large keys are readily available. At the same time, however, the most direct application of computer applications for dexterity limitations has occurred in mathematics education, where the computer has largely displaced the calculator, graphing implements, and the drawing of mathematical symbols on paper. Similarly, it has nearly displaced traditional pen-and-paper design techniques in engineering and architecture design studios. On the one hand, increasing use of computers in place of these other methods may represent a barrier if computers remain inaccessible. But with appropriate accommodations to make computer input accessible for individuals with dexterity impairments, the computer may prove more usable than these other methods. Furthermore, as a general-purpose information and communication technology essential to STEM education in all fields, computer accessibility is even more paramount.

Personal computer software represents another area where many accommodations (some provided by the students themselves) have emerged. One example directly relevant for dexterity involves the use of voice-to-text office dictation software, originally released in the late 1990s as an office

productivity tool. However, students with a range of disabilities, including impaired dexterity function, have used it successfully in lieu of manual note taking and transcription of recording lectures into notes. Diverging from the office dictation purposes for which it was designed, these novel uses further demonstrate the extent to which mainstream technologies may be adapted as accommodations (Fichten, Barile, & Asuncion, 2003, p. 208-209; Tumlin & Heller, 2004; Roberts & Stodden, 2005).

In terms of accommodations, technological developments historically have outpaced their implementation in the classroom. This gap has created problems due to a lagging adoption of technological accessibility solutions, and studies have noted the lack of training in their use by faculty and staff. Educators also have access to advanced software-based technologies for evaluating the efficacy of accommodations, but these are still not in widespread use (Crosby, 1981; Rule, Stefanich, Haselhuhn, & Peiffer, 2009). Nevertheless, a leading study of Canadian students with disabilities has credited the broad field of “information technology” with leveling the playing field for students. At the same time, the very rapid pace of technological change in STEM education suggests that the field may not stay level. Entirely new categories of laboratory equipment, discussed below, have

become available over the past decade, but many of these devices have yet to be evaluated regarding their accessibility for students with impaired dexterity function (Fichten et al., 2003, p. 208).

Despite problems of lagging adoption, researchers have pointed to the potential of specific software tools to enhance STEM education for students with disabilities, especially in the field of mathematics. Observing that many consumers who receive vocational rehabilitation are poorly prepared in math and computer skills, and noting the need to improve the computer and mathematical literacy of these individuals to make them more competitive in the job market, Stoddard and Nelson (2001) have called attention to a number of specific software tools. Options range from proprietary applications such as MathPad, a set of modules with built in accessibility options for students with physical and learning disabilities, to freely available websites such as PlaneMath, a NASA-sponsored service designed to teach math to students with disabilities.

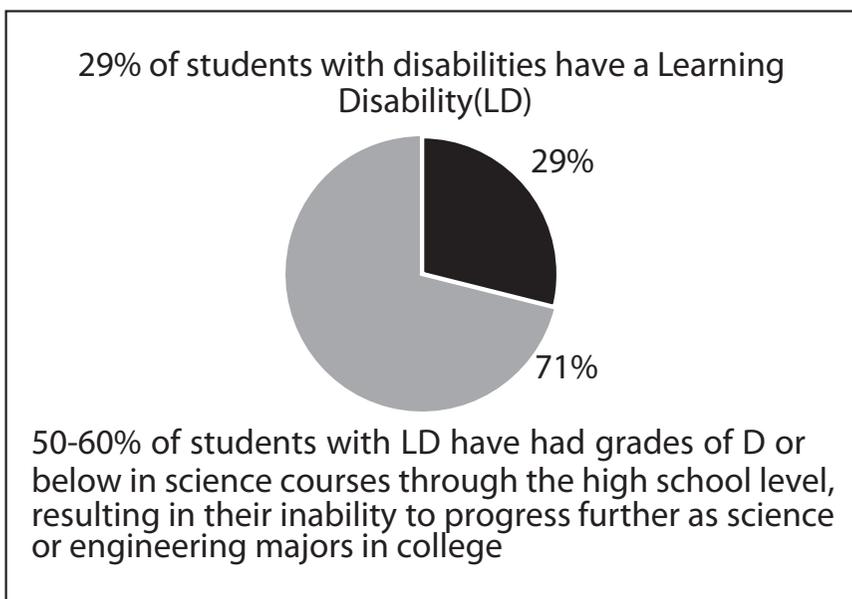
COGNITIVE AND BEHAVIORAL FUNCTION

Learning Disabilities and Attention Deficit/Hyperactivity Disorder

According to federal statistics from the 1990s, the most

common disabilities among U.S. students are learning disabilities (LD), affecting over five percent of the overall population (Norman et al., 1998). Because LD frequently is discovered or emerges late in the course of students' education, 29 percent of adult students in colleges and universities with disabilities claim some form of LD (Horn & Berkold, 1999) (See Figure 2.5).

Figure 2.5

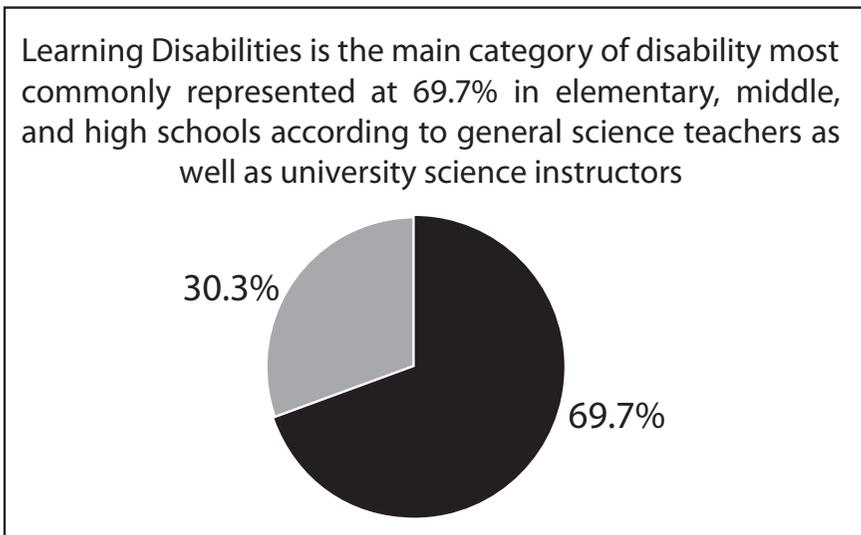


Unfortunately, the high incidence of LD is matched by underperformance and underrepresentation of these individuals in STEM education and careers. Historically, between 50 and 60 percent of students with LD have had grades of D or below in science courses through the high school level, resulting in their

inability to progress further as science or engineering majors in college (Cawley, Kahn, & Tedesco, 1989; Donahoe & Zigmond, 1990).

In order to understand further practices involving science education of students with LD, Norman et al. (1998) undertook an important study in the late 1990s that provided much of the available knowledge on the subject.

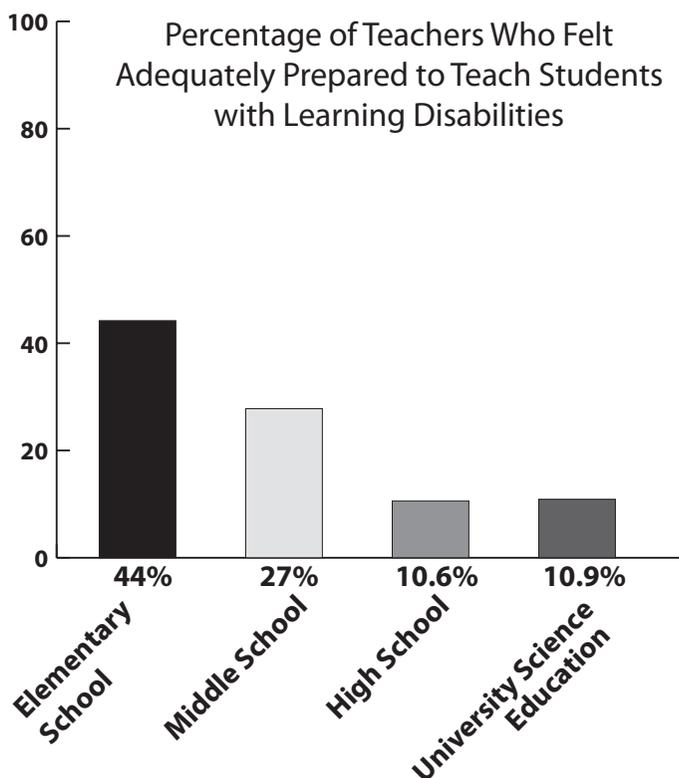
Figure 2.6



STEM faculty at all levels—elementary, middle, and high school general science teachers, as well as university science instructors—reported LD as the category of disability most commonly represented in their classrooms, comprising almost 70

percent of disabilities (Norman et al., 1998) (See Figure 2.6). Yet, as the frequency of LD reported increased at the higher grades, especially the secondary and postsecondary levels, the less information was available to these educators about their students' learning capabilities and accommodation needs.

Figure 2.7



While 44.2 percent of elementary educators believed they were adequately prepared to teach students with LD, only 27.8 percent of middle school teachers felt similarly confident. Even more

staggering was the finding that only 10.6 percent of high school teachers and 10.9 percent of university science educators believed they were prepared to teach these students (Norman et al., 1998) (See Figure 2.7).

Steele (2008) has noted that because learning disabilities are frequently mild and because many students with LD have average to very high intelligence, these learners are able to enroll in mainstream science education courses. Their inclusion in such environments, however, does not mean that learning is free of challenges. Students with LD generally have at least one type of processing disorder. The most common of these are visual processing disorders that may impede understanding of the graphical elements of learning, such as chalkboards/whiteboards, PowerPoint slides, overhead documents, or textbook graphics, as well as their content, such as bar, circle, and line graphs. Auditory processing disorders also are common and may present problems with lectures, discussions, and group work. In addition to processing disorders, students with LD frequently contend with memory impairments that complicate processing. Memory issues, in particular, can make skills testing a major challenge.

In addition, students with LD often struggle with one of the basic academic skills—mathematics, writing, and reading—

that are the building blocks for more multifaceted courses such as science. Hence, a student who has reading difficulties may not possess an optimal foundation to understand terminology essential to a given science unit. Learners with writing problems may not be able to convey thoughts and ideas in a science curriculum that increasingly emphasizes critical problem solving and inquiry as a mode of learning. Finally, while mathematics difficulties pose obvious challenges in courses such as algebra and calculus, they also impact courses such as chemistry and physics where students must be able to calculate electronegativity and chemical reactions.

In addition to issues of sensory processing and challenges with one or more of the basic academic skills, Lerner and Kline (2006) and McNamara (2007) have called attention to some of the other challenges that learners with LD may encounter. There are issues of organization and attention, particularly among students with attention-deficit/hyperactivity disorder (ADHD). Steele notes that such students may have problems with completing long-term assignments, tracking daily work, and maintaining appropriate study materials. Furthermore, these learners often have trouble focusing in the classroom and laboratory and reading continuously when studying.

While frequently considered a distinct condition, attention deficit/hyperactivity disorder (ADHD) shares many characteristics with LD. ADHD is generally characterized by hyperactivity, inattentiveness, and impulsiveness. The symptoms of ADHD are only considered clinically meaningful, however, when they measurably exceed the behaviors of other individuals within a particular age group. ADHD is most commonly associated with children and adolescents and research suggests that about five percent of school-aged children in the United States have the disorder. However, ADHD is also increasingly diagnosed in adults, many of whom went undiagnosed as children. ADHD is typically managed with stimulant drugs, the most common of which is methylphenidate, introduced as Ritalin in 1955. During the past half-century, Ritalin has remained the most popular drug for the management of ADHD, with estimates of up to five million children using the medication in 2000 (Critser, 2005).

As more Americans have been diagnosed over the past two decades, ADHD has been increasingly recognized as a disability and some disability activists have argued that information on ADHD is scarce because the disorder was not categorized as a disability in special education until recently, which limited the amount of funding provided for research. These activists contend

that educators have had to rely on treatments for learning or behavioral disabilities that may not address the particular needs of students with ADHD.

Individuals with ADHD have gained disability rights in the United States as part of two major laws. First, Section 504 of the Rehabilitation Act of 1973, a civil rights law, requires that schools and any other program receiving federal assistance not discriminate against anyone with a physical or mental impairment that limits a “major life activity.” Second, the Individuals with Disabilities Education Act (IDEA) mandates that eligible children receive access to special education and related services through individualized programs. In 1991, the Department of Education issued an official memorandum designating ADHD as a covered disability under both Section 504 and IDEA recognizing that those diagnosed with ADHD are entitled to reasonable accommodations under the law.

Accommodations

Accommodations for students with LD and ADHD are typical for classroom and lecture-class situations across STEM fields and other disciplines. To meet the specific instructional needs of learners with LD, science teachers could establish

collaborations with special education teachers to develop strategies to determine and address the learning accommodations needs of individual students. For example, Morocco, Clay, Parker, & Zigmond (2006) note that general science teachers and special education teachers may work in tandem, whereby instruction is primarily delivered by the science teacher and then is clarified and reinforced through discussion of key ideas in smaller groups led by the special education teacher. Alternately, Grumbine and Brigham Alden (2006) note that both teachers may coordinate instructional activities in the same classroom.

In the area of science education, Steele expresses a preference for classroom modifications and learning accommodations based on UDL concepts, with the intention of improving learning for all students in the mainstream classroom. For example, classroom pedagogy and activities based around a single, unifying theme in science may benefit students with LD who have memory, attention, or organizational skill deficits, as well as improve instruction for the class as a whole. This approach has also been advocated by the National Science Education Standards, which recommends the use of major themes such as change, environment, and inquiry in secondary-level science courses (National Research Council, Center for

Science, Mathematics, and Engineering Education, 1996). Steele supplements this suggestion by noting that unit-specific themes in science, such as pollution and conservation when learning about water, may be utilized.

As for resources to actualize this approach, Friend and Bursuck (2006) point to the use of “advance organizers” such as study guides, charts, and graphic displays to reinforce central concepts. Other pedagogical strategies rooted in UDL that may benefit science students with LD include an introduction of vocabulary and key terms at the beginning of each lesson, teacher use of explicit prompts, organizational cues, and bridging phrases when lecturing (i.e. “an important point to remember” or “the next step in the experiment”), and real-life examples to illustrate important concepts.

Another area of concern involves out-of-class learning, such as textbook reading and homework assignments. Many students with LD often exhibit below average reading skills, which are further compounded by the complex, if not confusing, layouts of high school science textbooks (Steele, 2008). Strategies for assisting with textbook reading generally have focused on organizational aids. For example, teachers can explicitly go through the textbook to point out elements that may be of use

to students, such as summaries, introductory objectives, and questions. If needed, they may go even further to review textbook readings in order to highlight main ideas and key concepts, clarify any confusing graphical elements, and assist students when memorization of certain facts is necessary (Friend & Bursuck, 2006; Polloway, Patton, & Serna, 2005). If these strategies prove inadequate, teachers may also consider supplementing textbook readings with chapter notes that will facilitate learning essential material and overcome challenges with its delivery via textbook (Grumbine & Brigham Alden, 2006). An added benefit of notes is their ability to be reused in subsequent classes and their usefulness for all learners in the classroom.

Another method of addressing difficulties that students with LD may face with textbook reading assignments is the Read, Imagine, Decide, and Do (RIDD) strategy (Jackson, 2002). While more frequently recommended for students in elementary and middle grades, even students in secondary education may benefit from this approach. One advantage of RIDD is its cross-content versatility, enabling it to be used in a variety of courses with a reading component. Another appeal is its simplicity for teachers and students who may find other strategies too difficult or too time-consuming to master. The four steps involved in RIDD:

1. R – “Read the passage from the first capital to the last mark without stopping,” which forces readers to focus on the entire task of reading rather than taking a line-by-line approach to the assignment.
2. I – “Imagine or make a mental picture of what you have read,” which assists students to transform content to be learned into meaningful visual, auditory, or kinesthetic images of information.
3. D – “Decide what to do,” which refers to specific actions that may need to be taken, such as operations to complete a word problem or using a dictionary to ascertain word meanings that may be unclear.
4. D – “Do the work,” also derived from math word problems but equally applicable to science, this step refers to students completing any task at hand (Jackson, 2002).

Regarding homework assignments, Polloway, Patton, and Serna (2005) point to the need for clear directions, delivered both orally and in writing, for students with LD. Special education teachers who work in coordination with general science teachers can enhance this effort by assisting with and monitoring homework progress on an individual basis. Large projects and complex assignments may benefit from the use of

intermediate due dates. Because homework is essentially a self-directed learning activity that places increased responsibility on the student, some authors have suggested that broad-based interventions to improve self-management are essential (Smith, Dittmer, & Skinner, 2002; Steele, 2008).

Finally, there is the matter of testing accommodations. While science education's emphasis has become less fact-oriented in recent years in favor of critical inquiry and mastery of broad concepts, assessment is still driven by high-stakes testing that has become more common in the wake of the No Child Left Behind Act at the middle and high school levels. As such, there remains a need to ensure that students with LD receive appropriate accommodations to assess, fairly and accurately, their skills and knowledge on tests.

Extended test time is the most frequently requested accommodation among students with LD. As such, disability service providers and educators must be informed about the need for and appropriateness for this accommodation. To assist these individuals in determining the reasonableness of extended test time, Ofiesh, Hughes, and Scott (2004) developed a model to inform the decision-making process that takes into account,

1. students' diagnostic classification

2. courses or classroom test to be accommodated
3. student interviews

This six-step model involves,

1. determining appropriate criteria through a firm statement of diagnosis
2. identifying academic areas where problems may exist
3. using diagnostic test scores to determine the functional impact of the LD
4. comparing this impact against the course or test to be accommodated
5. evaluating the severity of the disability to determine how much additional time to provide
6. evaluating unique factors and synthesizing information

Because students with LD, especially at the postsecondary level, most commonly have problems with basic math calculations and application, more time may be warranted to help students demonstrate their knowledge. Models such as this one may assist in determining the appropriateness and nature of extended time as an accommodation.

Where standardized tests are concerned, recommendations include encouraging students with LD to preview the entire test before beginning to answer questions, so

that they can plan ahead for the test's sections. Those students who have organizational and attention problems may potentially benefit from this approach, as many of them may become so focused on one section that they leave questions in other sections unanswered before time runs out. As such, these students might place a checkmark next to difficult items as a reminder to return to these questions (Bos & Vaughn, 2006; Steele, 2008).

Another issue involves the various types of questions that students may encounter on standardized tests, including multiple choice, essay, and true-false questions. Here, students with LD may benefit from practicing each question type and learning specific strategies for dealing with these items. Learning key words and eliminating obvious answer choices that cannot be correct may help with true-false and multiple-choice items. The commonly used "five paragraph" method, involving an introductory paragraph with a thesis statement, three supporting paragraphs, and a conclusion, may provide a useful strategy and template for answering essay questions (Bos & Vaughn, 2006; Steele, 2008).

Postsecondary Science Education and Learning Disabilities

As the most common type of disability encountered in university education, comprising 46 to 61 percent of all

disabilities, LD has received a great deal of attention from scholars (Wolanin & Steele, 2004). While enrollment of these students in postsecondary programs increased during the early 2000s due to better academic preparation, improved transition plans, and an increased availability of financial aid, the actual retention and completion of degree programs by these students failed to follow the same pattern. Many students drop out in their first year of study.

In order to make sense of the expanding literature in this area, Orr and Hammig (2009) undertook a literature review and meta-level analysis to discern inclusive pedagogy for students with LD, with a particular emphasis on UDL approaches for accommodating these students. Their broad-based survey of 38 articles, books, chapters, and reports, resulted in the identification of LD interventions that, while general in scope, have relevance for STEM education. Of particular importance, Orr and Hammig found, was the emphasis the literature has placed upon backward design, multiple means of presentation, inclusive teaching strategies and learner supports, inclusive assessment, and instructor approachability and empathy.

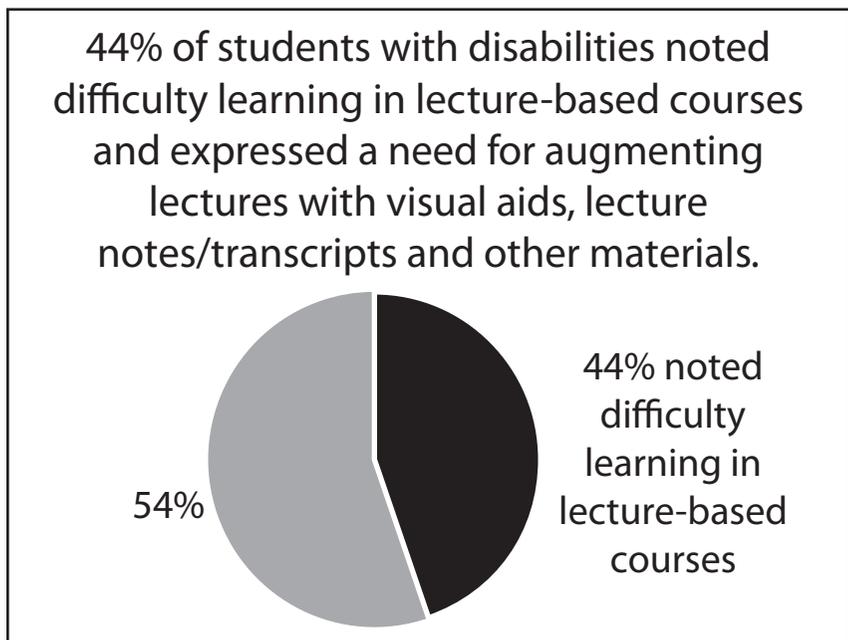
Backward design, which refers to pedagogy that begins with the formulation of learning goals and objectives, has been

identified as one possible intervention for students with LD. Faculty members first identify the desired learning outcomes, including the material that students should have proficiency over and understand, and then develop teaching approaches and strategies, including assessments, to realize those outcomes. In support of this approach, scholars recommend providing detailed course syllabi and readings lists at the beginning of the term, supplemented by follow-through with clear and consistent expectations of requirements throughout the term. For example, a mathematics class involved a focus on goals that were customized to each student with learning benchmarks. A computer-based psychology course focused on the utilization of short-term and long-term goals to realize the mastery-based course design.

Multiple means of presentation, which refers to offering course content and information through several modes, such as visual (i.e. textual, video, graphical) and oral approaches, are often used in order to reinforce learning. This idea is one of the central tenets of UDL and is prescribed consistently in the literature for students with physical, perceptual, and cognitive impairments. The effectiveness of multiple means of presentation has been illustrated in one study of a college-level algebra course that found a videodisc (interactive video) presentation to be more

efficacious than a traditional, textbook-based means of delivery. In a survey (Fuller, Healey, Bradley, & Hall, 2004) of students with disabilities (See Figure 2.8), 44 percent of respondents noted difficulty learning in lecture-based courses and expressed a need for augmenting lectures with visual aids, lecture notes/transcripts, and other materials to facilitate delivery of course content.

Figure 2.8



Yet, while this approach is frequently recommended, authors have also noted the potential for such a cognitive load, due to multiple simultaneous presentations of the content, to be taxing on students with dyslexia. Hence, while this approach has widespread

acceptance in the literature, mitigating factors may preclude its ubiquitous application in all teaching activities.

In addition to the use of multiple formats, UDL approaches also recommend the use of a variety of instructional strategies. Also known as “accessible pedagogy,” this strategy refers to teaching students in the most inclusive way possible. For example, in order to overcome accessibility barriers associated with lectures, the use of guided notes (lecture outlines on which students fill in details) was found to result in improved performance. The use of the pause procedure, where pauses for discussion are placed within a lecture, was also found to be effective. Regarding study aids, organizational aids such as graphic organizers, as well as reading guides, chapter outlines, and study guides, were found to contribute to improved learning. In the area of writing assistance, approaches such as precise assignment instructions, clear explanations for required assignment formats, use of smaller assignments when dealing with a larger project, and provision of more lead time, were found to be effective. The literature has also recommended embedding some form of course-specific writing support into the structure of the course, though noting that college writing centers have tended to offer variable results. Finally, strategy instruction, in which proofreading, mnemonics,

organization, and other methods are used as strategies for learning and as accommodations for students with LD, have some degree of efficacy.

DEVELOPMENTAL DISABILITIES

Developmental disabilities comprise a wide array of conditions. Our discussion limits itself to four in particular: developmental dyscalculia, Asperger's syndrome/autism spectrum disorder, Williams syndrome, and spina bifida. Some other major categories of developmental disorder typically result in severe cognitive limitations that prevent most students from proceeding beyond the most elementary STEM courses. Established research to discover how developmental disorders affect the ability of students in STEM classes has tended to compare students with developmental delays or deficiencies against non-disabled peers of the same chronological age. However, more recent studies compare students with developmental disabilities with peers considered to be of comparable cognitive and intellectual development, regardless of age. This work suggests that children with developmental disorders process information in a fundamentally different way from students without developmental impairments. Such an approach is

intended to develop the most promising practices for enhancing the educational experience for students with developmental disabilities. However, these studies are still in their infancy.

Despite the fact that students with severe cognitive disabilities may not be able to participate in the general curriculum, these learners nevertheless deserve the benefit of science instruction. Spooner, Ahlgrim-Delzell, Kohprasert, Baker, & Courtade (2008) discuss the lack of research on how to teach science for students with significant cognitive disabilities and the potential of alternate assessments to help address this issue. Their study notes that special educators frequently teach science more than they realize. Daily conversations about weather, for example, could be expanded from labeling the weather and discussing appropriate clothing to active investigations—comparisons of hot and cold, wet and dry, wind and storm. Also, common instructional activities on personal health and safety may be expanded. However, teaching science to these students will often require special education teachers to embrace hands-on styles of instruction in their classrooms.

Developmental Dyscalculia

Developmental dyscalculia is perhaps the most heavily

studied STEM-specific disability. Not only does this disability pose challenges for learning mathematics; the abstract thinking, problem-solving, and spatial reasoning associated with the condition apply to other fields such as engineering and computer science. While not strictly a developmental order (causes may include injury), its major causes are developmental in nature. Dyscalculia is often grouped with the federally recognized “specific learning disorders” (dyslexia, dyscalculia, dysgraphia, dyspraxia, auditory processing disorder, visual processing disorder, and attention deficit hyperactive disorder), several of which have been discussed previously as learning disabilities.

Mathematics disabilities frequently entail genetic, neurobiological, and epidemiological considerations (Shalev et al., 2001), yet developmental dyscalculia is typically understood as a brain-based disorder. Dyscalculia may be experienced independently of other disabilities, but it may also be encountered in conjunction with other disabilities, such as ADHD, developmental language disorder, epilepsy, and Fragile X syndrome. Research also has implicated poor teaching and environmental deprivation in the onset and exacerbation of these disabilities (Shalev, 2004).

Developmental dyscalculia is believed to affect five to six percent of the school-aged population, and it frequently persists as a disability into adulthood. About half of pre-teen students continue to experience dyscalculia into adolescence and early adulthood. At the same time, however, research into dyscalculia is relatively recent, and much remains to be understood regarding its precise etiology, diagnosis, treatment, and prognosis. As a disability, rather than a disorder, a great deal of research is needed to understand how dyscalculia is experienced by students, its impact on their learning ability, and the optimal ways to accommodate the disability.

The subjective experience of dyscalculia as a barrier to STEM education differs according to the level and type of math taught. In elementary mathematics, students may face problems with basic arithmetic concepts and exercises, frequently reflected in challenges with developing numeracy and difficulty with counting exercises. As math education progresses and students are expected to build upon their foundation of basic skills, difficulties become even more apparent. Students may have trouble with learning multiplication tables and understanding addition, subtraction, multiplication, and division. Even if students have acquired basic number concepts by this time and are fully

able to write, read, or correlate number words to numerals, they still may not comprehend solutions to number problems such as $39 - 13$ or 9×7 . Furthermore, some students may have difficulty with algorithms, both in terms of notation and function. Unintentional misuse of arithmetic signs, forgetting to carry over ones in division, transposing digits, or the inability to solve more complex problems are all issues that may be encountered by students with dyscalculia (Shalev, 2004). In fact, Shalev has called attention to the dissociation between knowledge of number facts and arithmetic procedures faced by many students with dyscalculia; paradoxically, these learners may master number facts but remain unable to solve complex mathematics problems.

Autism and Asperger's Syndrome

Autism is a spectrum of neural developmental disorders with characteristics that include communication difficulties and impairments in mobility and dexterity that may affect performance in STEM settings. Asperger's syndrome is a disorder within the autism spectrum, distinguished by difficulties in social relations and a restricted set of behaviors or intense interests. It is difficult to distinguish clearly between Asperger's syndrome and "high-functioning autism," or HFA. Asperger's is becoming more

commonly encountered at the college level as more of these students pass through inclusive classrooms at the high school level and are better prepared academically to enter college.

Students with Asperger's and HFA who do achieve well enough to matriculate routinely demonstrate very high apparent intelligence or skills in some areas. At the same time, they may be unable to pass certain courses. These students may possess extraordinary abilities to remember and recite lists, calculate in their heads, produce art, perform music, or master the content of textbooks. They also may have mastery of a very large vocabulary and communicate eloquently. Yet, they also may fail on tests and assignments or be unable to deal with relatively amorphous subjects such as literature. Such academic issues are compounded by problems in social interaction that affect team-based assignments and group work, physical clumsiness that impacts performance in field, studio, or lab work, poor handwriting, and other challenges.

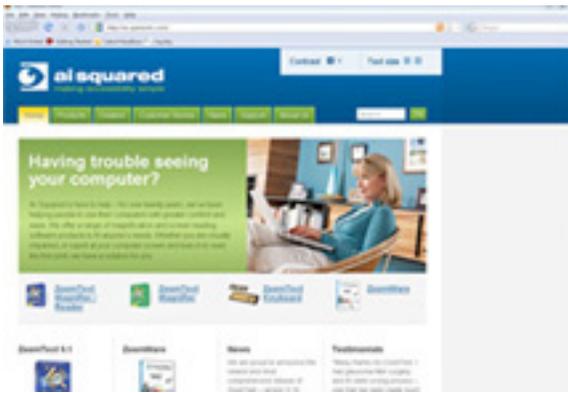
Asperger's and HFA sometimes are considered "invisible" disabilities like ADHD or LD, meaning that instructors, primarily at the postsecondary level, may not be aware that students with autism are enrolled in their class unless they self-identify. Thus, recommendations for accommodations should begin with an

approach toward inclusivity. Instructors should be aware of the possibility of encountering autism in the classroom at any time, and they should be encouraged to be open-minded, welcoming, and available.

UDL classroom techniques can also go far to improve these students' classroom performance. Providing alternatives to handwritten note taking, such as allowing laptop usage or, in some cases, permitting the use of a note taker, can mitigate the effects of poor handwriting skills. Accessible versions of in-class presentations may also improve outcomes for these students. Electronic slideshow presentations such as PowerPoint may be made available on the web before class begins. This allows students to preview the presentations, view them on their laptop computers, and review them later without having to rely solely on class notes. For students with disabilities, advance access to PowerPoint presentations can enable them to read them utilizing accessibility software, including screen readers (e.g. JAWS) or text enlargers (e.g. ZoomText, see Figure 2.9), on their personal computers. For similar reasons, instructors may wish to select textbooks that are available in an accessible e-reader format, because these texts can support screen readers. Accessibility software such as screen readers, although originally intended for

blind students, are useful for students with autism because they may use the software to “listen” to print materials as a learning strategy (Fichten et al., 2009).

Figure 2.9
ZoomText Magnification 1x



ZoomText Magnification 8x



Photo Credit: <http://www.aisquared.com/>

Generally speaking, instructors should consider making use of the web-based course-management systems adopted by many universities in order to provide syllabi, assignment instructions, and other communications with their classes. Many course-management systems provide affordances and tools over and above the simple provision of online text. In addition to their relative accessibility compared to paper versions, the ready availability of these online resources assist students with autism, as well as their parents or assistants, with managing day-to-day STEM learning activities. While some systems may pose usability challenges, the potential advantages often outweigh these risks.

In preparing lectures or lab instructional sessions, instructors should consider other UDL-based approaches such as the use of study guides. Where appropriate, they may wish to create charts and graphics to provide additional ways to reinforce important concepts (Friend & Bursuck, 2006). Lecture techniques should include identification of key passages in textbooks and explanation of complex graphics in teaching materials. The ability to “read between the lines” of a text, graphic, or lecture may seem like an exercise in “common sense,” well within the ability of the average student, but this assumption may create barriers for students with autism, who may not be able to readily discern the

intended relevance of graphical data (Orr & Hammig, 2009). In addition to also benefitting students with visual impairments or LD, these explanations may reduce undue cognitive loads for all learners in the STEM classroom and lab.

Similarly, although the university experience involves finding one's own way through complex assignments, students with autism may benefit greatly from clear and precise directions, especially when delivered in multiple formats (i.e., orally and written). This suggestion also applies when discussing expectations for examinations (Polloway, Patton, & Serna, 2005). Instructors assigning longer-term projects such as research papers should not assume that students have successfully completed a project of this complexity before. Students with autism, in particular, can benefit from relatively detailed, in-class discussions of time-management and research techniques, yet all students may profit (Smith, Dittmer, & Skinner, 2002; Steele, 2008). Testing or assignment completion also may require that the student be given a distraction-free environment similar to those recommended for students with ADHD and LD (Steele, 2008).

Students with autism often encounter some level of impaired mobility or dexterity function that may present as general "clumsiness." While little research exists on the subject

of accommodation for these cases, these students may need minor accommodations similar to those provided for those with mild mobility or dexterity limitations. For example, fieldwork or laboratory procedures such as working with chemicals, flames, or hot substances may be more problematic or dangerous for these students. In these cases, instructors may have students work in teams for labs, where duties may be assigned according to each student's strongest abilities (Stefanich, 2007a, pp. 154, 248).

Williams Syndrome

Williams syndrome is a developmental disorder that leaves a person's verbal skills relatively unaffected while severely impairing visuospatial perception. In addition, students with Williams syndrome commonly have social problems but are generally "sociable." They may experience cognitive or intellectual impairments severe enough to limit success in higher-level STEM education, but others experience only very mild disabilities of this nature. With these characteristics in mind, O'Hearn and Luna (2009) conducted a study on students with Williams syndrome to determine how these students process mathematical information. Their research examined different methods of processing information related to magnitude (i.e.

“how much” and “how many”), as well as the effect it had on people with Williams syndrome, whose neurological development often prevents effective mathematical computation. This study concluded that students with Williams syndrome struggled with basic mathematical function, particularly in questions involving magnitude, lagging behind their cognitively matched peers. However, they outperform that same group regarding verbal aspects of math, such as reading and writing numerals (O’Hearn & Luna, 2009). Another study with older adults with Williams syndrome suggests that these magnitude-related mathematical skills can improve over time, but do not outline specific pedagogical methods for improving mathematical function (O’Hearn & Luna, 2009).

Agenesis of the Corpus Callosum (ACC)

Agenesis of the Corpus Callosum (ACC) is a symptom of a number of different conditions that are often described separately. Spina bifida, a disorder of the spinal cord that can also cause lower body paralysis, is also associated with hydrocephalus and ACC, both of which may create learning difficulties. Students with ACC who have average or above-average IQs still encounter social, behavioral, and problem-solving challenges similar to Asperger’s

or autism. Individuals with spina bifida also face mobility and dexterity impairments that adversely affect their educational experience (English, Barnes, Taylor, & Landry, 2009; Fletcher et al., 1996).

By the time they reach adolescence, students with ACC tend to exhibit difficulty in mathematics, while often having grade-level or better skills in reading. Studies that have focused on the cognitive abilities of students with ACC have found that problems with working memory adversely affect mathematical performance. However, early instruction for specifically targeted mathematical concepts can provide students with spina bifida with the most promise for effective learning for students with these disorders.

Developmental conditions such as ACC and Williams Syndrome primarily affect a student's ability to perform mathematical and problem-solving functions, leaving verbal and reading skills relatively unaffected. Hence, courses such as chemistry and biology, which combine reading and mathematical processes in classroom instruction, may also necessitate some hybrid instructional approach to address these students' unique educational needs. Further, the issues these students experience with problem solving present a major barrier to problem-

based pedagogy of the type that is currently dominant in STEM education. It is worth mentioning that while findings based on people with more severe developmental disorders may inform the pedagogy of STEM educators, they are unlikely to encounter such students, especially in postsecondary and university settings.

COMMUNICATION DISORDERS

Communicative function encompasses both “expressive” communication such as speech and writing and receptive communication such as reading, hearing, and auditory processing. Regarding the accommodation of STEM learners with disabilities, speech-related and other communications disabilities tend to be somewhat overlooked. For purposes of this literature review, speech function in adolescents and adults consists of the ability to select appropriate words from memory, form them into coherent sentences, and articulate them as speech. Effective speech communication in STEM classrooms may require effective public speaking skills, as well as the ability to communicate with other members of lab groups, design teams, and instructors by using speech. Other communication disorders likely to be encountered in secondary and postsecondary STEM education include dysphasia, dysnomia, and dysgraphia.

Dysphasia and apraxia of speech are conditions that involve the partial loss of one's ability to produce speech. These disabilities are marked by the inability to speak certain words or sounds, substitution of incorrect sounds in place of correct ones, inability to speak grammatically, poor enunciation, or unusual intonation. For example, strokes are a leading cause of acquired dysphasia in people under 30 (Bruce et al., 2006). However, only students with mild aphasia would progress to the stage where they would be likely to enter college (Bruce et al., 2006, p. 138). Aphasia may coexist with other functional impairments, including dexterity disabilities affecting handwriting and keyboarding, socialization problems, loss of sensation, or other conditions. Dysnomia, or the inability to remember the correct word when it is needed, affects writing and speech. It may be caused by a traumatic brain injury, or it may be part of an inherited speech disorder. Dysarthria is essentially poor pronunciation and generally is caused by a neurological disorder. Each of these disorders poses obstacles to a range of formal and informal classroom activities that involve speaking. Dysfluency, which is characterized by stuttering, ranges from the repetition of certain words that are barely perceptible by the listener, to long pauses that may make normal speech communication impossible.

Related to these conditions are others, such as expressive language disorder, where students typically have good comprehension and written language skills, but exhibit vocabulary, word-memory, or complex sentence construction that is below expectations for their age or education level. Classroom accommodations for these forms of expressive disorders include allowances for extra time to complete oral presentations. A more UDL-oriented accommodation for courses that traditionally involve oral presentations would allow alternative forms of presentation for students who would be assisted through their use. However, this solution would not necessarily work well in encouraging effective speech communication in the impromptu conversations typical of class discussions or during laboratory exercises.

Dysgraphia is a deficiency in handwriting ability that also sometimes involves incoherent constructions. Students with dysgraphia who have difficulty writing clearly may, for example, be accommodated through the use of word processing software. This is an area that would benefit from further study.

In severe cases of expressive disability, students can use electronic alternative and augmentative communication (AAC) systems. While there is a relative paucity of research on STEM-

specific classroom accommodations for these disabilities, their nature suggests that accommodations usually prescribed for similar conditions might apply successfully.

CHAPTER 3

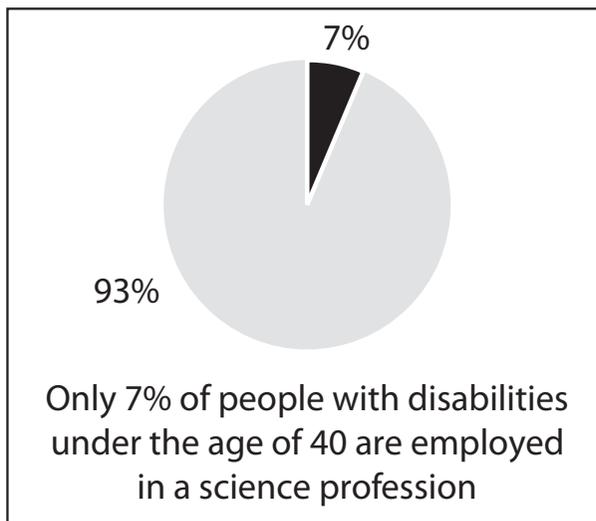
STEM DISCIPLINES AND THEIR ACCOMMODATION

INTRODUCTION

Students with disabilities are underrepresented in STEM education and, later, as adults in STEM professions. This underrepresentation has been attributed to a variety of factors. First, informal exposure to science educational experiences has been attributed to the development of a lifelong interest in science. Young people who, because of disability, lack some access to informal education may never develop such an interest. Second, a lack of elementary level teacher training in accommodations and inclusive classroom techniques in STEM may create barriers for students with disabilities, and as a result, they may fail to develop a strong interest in these fields. Whatever the reasons, by the time they reach middle school, many students with disabilities are represented less within STEM education. Melber and Brown (2008) note that although students with disabilities comprise 12 percent of the general student population, they are not correspondingly represented in science-related professions. A 2004 study by the National Science Foundation revealed that only seven percent of

people with disabilities in science professions are under the age of 40 (Melber & Brown, 2008) (See Figure 3.1). These findings suggest that educational institutions have not improved the possibilities for people with disabilities in recent decades, regardless of these learners' inherent aptitudes or abilities. This chapter outlines the kinds of science classroom and lab accommodations that have proven effective, based on recent research.

Figure 3.1



For the purposes of this study, we make a number of assumptions about the nature of STEM education. First, we assume that nearly all STEM education has two basic elements: classroom lectures and laboratories. Both may occur in the same

physical space, but the nature of pedagogy is different for each. Thus, the nature of disability accommodations differs. We also assume that, generally speaking, classroom accommodations (as opposed to lab accommodations) for students with disabilities are more-or-less uniform across most fields of science and engineering. For example, speech-to-text software works approximately the same way whether a student is in middle school or college, or studying biology or physics. The literature supports this generalization, even though it also emphasizes that there are many exceptions that pertain to particular fields. In contrast, laboratory settings tend to exhibit the greatest variability from field to field. Hence, this chapter examines STEM education discipline-by-discipline, complementing the disability-specific approach taken in the previous chapter.

GENERAL COMMENTS ABOUT ACCOMMODATIONS IN STEM DISCIPLINES

Two recurring themes figure prominently in the accommodation of learners with disabilities within the STEM fields. First, the visual nature of learning in these disciplines has far reaching implications, not only for students with impaired visual function, but also for a wide array of disabilities ranging

from LD to autism. Second, STEM education tends to be defined by a “hands-on” approach that emphasizes experiential learning. Whether for numeracy in math or fieldwork in biology, inclusive approaches to insure maximum participation in learning are as fundamental as the provision of classroom accommodations.

First, it is necessary to acknowledge the dominance of visual learning within STEM and how graphical approaches to instruction may impact students with disabilities. Fraser & Maguvhe (2008) argue that students who are completely blind or near-blind are particularly challenged in their primary education, due in part to the role that rich visual stimuli often play in the development of conceptual thinking abilities. As such, visual impairments may go beyond the issue of sight to have far-reaching implications for cognitive development and engagement. If not accommodated or otherwise resolved, limited vision function may result in negative learning outcomes among STEM students with disabilities. One possible intervention for this problem has been offered by Wu, Krajcik and Soloway (2001), who claim that haptic models can substitute for the eyes to allow the development of a sort of “visionless visualization.”

Several other studies examine or at least allude to this problem in non-visual contexts. It is not clear from the literature

whether it is safe to assume that students with disabilities who have demonstrated their academic aptitude by the beginning of high school have, in fact, completely caught up to the sighted peers and are well-prepared for the next stages of their education. Compounding this lack of information is the documented fact that they may be discouraged from pursuing STEM courses at the high school level, perhaps because of assumptions about the difficulty of accommodating them, resulting in a lower level of preparation for college-level courses (Kapperman et al., 2002; Fraser & Maguvhe, 2008). This possibility hints at the difficulties in assessing the intersection of social factors and physical impairments when attempting to account for students with disabilities' success at the high school level, and their underrepresentation among STEM students and degree holders at the university level.

A second general issue across STEM fields is the "hands-on" problem. Training in numeracy, problem-solving, and related skills that begins at the elementary level gradually gives way to increasingly advanced mathematics instruction in middle school and beyond. Except for mathematics majors, math education typically ends after about the second year in college. Yet math education is a fundamental precursor for all the other fields

discussed in this volume, so its importance cannot be overstated, especially as math presents a special set of problems for students with disabilities.

Starting in middle and high school, as students progress into higher mathematics, they begin to face much greater challenges in science and (later, in college) engineering. These fields have a strong tradition of emphasizing various forms of physical training beyond the classroom, including such things as studio design, laboratory experiments, the construction of working models or prototypes, or the performance of work in “field” settings such as nature for the sciences, or in industrial settings in engineering (Supalo et al, 2008). As Hall et al. (2002) show, not all of the barriers to this kind of education are environmental; some are self-imposed. Researchers have determined that many students with disabilities shy away from field work because they feel inadequate or awkward trying to undertake it.

The barriers associated with these experiential approaches to learning affect a much broader segment of the student population. The feminist critique of the laboratory/fieldwork-oriented type of education claims that these activities are based on longstanding masculine cultural ideals that discriminate

against, or at least discourage, the inclusion of women. According to this theory, laboratories and fieldwork also cultivate a culture of physical fitness and prowess, presumably based on masculine values, and as a result STEM education discriminates against people with disabilities regardless of gender (Hall et al., 2002). While such a theory may be rooted in feminist critique, it also may inform our understanding of the reasons for the negative educational outcomes in STEM fields for students with disabilities, as well as the pedagogical or institutional inertia that reformers face as they try to develop accessible alternatives.

Regarding the relationship between these experiential approaches to STEM education and accommodation strategies for students with disabilities, the literature frequently cites human assistants or helpers as viable solutions. Such assistants perform numerous functions in classrooms, such as serving as note takers or sign-language interpreters. In laboratories and other “hands-on” settings, they are regularly prescribed as a solution for students with limited dexterity, vision, hearing, or other functions. A body of STEM education-specific literature discusses how assistants have been effectively utilized as disability accommodations (Flick-Hruska & Gretchen, 1992, pp. 19, 37-38; Miner et al., 2001, p. 67; Webb, 2008, p. 199). At the same time, however, this approach

may conflict with the idea that participation is a key element in learning. It is unclear whether a student can experience “full participation” when he or she becomes a mere observer in an exercise that is intended to place the student in a physical or visceral relationship with equipment, machines, computers, specimens, and so on. In a similar vein, group learning activities based on the premise of dividing tasks according to functional ability have currency as another way to include students with disabilities in team approaches to lab work and class projects (Goodman et al., 2002, p. 82; Neely, 2007, pp. 1698-1699; Heller et al., 2008; Burgstahler & Bellman, 2009). While the team approach may enhance participation in student groups, it is unclear whether it simultaneously distances students with disabilities from the material experience upon which hands-on education is premised.

INFORMATION TECHNOLOGY AS AN ACCOMMODATION

Computer-based accommodations have become increasingly common not only for STEM education, but within the entirety of education, across all fields and at all levels. Information technologies may function as accommodations themselves, or they may serve as assistive technologies to render computers accessible to users with disabilities. As Asuncion, Fichten, Barile,

Fossey, and Robillard (2004) points out, personal computers now play a part in the entire educational experience, inside and outside the classroom, throughout K-12 education and persisting all the way through university study. That said, the potential of the computer to enhance the learning experience may be offset by a number of factors, such as problems of implementation by untrained or inexperienced teachers (Fichten et al., 2009).

Over the last two decades, modifications of personal computer hardware have given way to the development of software-based solutions to make computers accessible for people with disabilities. Before the widespread adoption of word processing, presentation software such as PowerPoint, and Web browsers, students generally had to make do with a professor's photocopied study notes or reading materials. They frequently had to rely upon their institutions to provide accommodations such as note takers or transcribers for recorded lectures. Widespread adoption of the personal computer created the possibility for distributing a greater variety of classroom documents electronically, as well as provided opportunities for instructors to create accessible versions or allow students to access them with accessibility software. Equally important, if not more so, has been the development and integration of

accessibility features within mainstream software applications, particularly office productivity software. Asuncion et al. have observed that the greatest increase in their use, particularly PowerPoint, has been among instructors, who have almost universally adopted them as teaching aids at the postsecondary level. Yet professors do not always consider issues of accessibility when they create websites, develop PowerPoint presentations, or use course management systems. Taking the approach that “e-learning” encompasses nearly any computer-mediated education, Fichten et al. (2009) surveyed students regarding the barriers they had encountered. They discovered that accessibility of electronic documents such as PDF files and course-related web sites were the top complaints.

More recently, the literature on computer-based accommodations for people with vision impairments has begun to focus on electronic book readers, such as the Amazon Kindle and Apple iPad. Such readers provide for the delivery of text content, while allowing students some control in terms of adjusting font sizes, zooming photos, and changing colors or contrast. While some argue that e-readers represent a great improvement in terms of accessibility, others point out that the choice of an e-reader poses unforeseen consequences.

Several universities were involved in litigation in 2010 involving their attempt to switch from paper textbooks to e-readers, a cost-saving measure that had the unintended result of making texts inaccessible to some students with vision impairments. In response, the U.S. Department of Education issued a letter to university and college presidents, urging them not to mandate the adoption of Amazon's Kindle e-reader by students because of its lack of tactile controls (U.S. Department of Education and U.S. Department of Justice, 2010). In summary, while there may be some potential for electronic book readers, debate remains on their specific level of accessibility.

GENERAL MATH AND SCIENCE CLASSROOM ACCOMMODATIONS

When students with disabilities encounter assignments or other learning activities in which accommodations are necessary for participation, they are frequently excused from the assignment (Scruggs, Mastropieri, & Okolo, 2008). But a variety of pedagogical techniques and assistive technologies exist to accommodate and include students with disabilities within the general science classroom. Within the K-12 environment, students with documented disabilities should receive accommodations as

part of their individualized education plans (IEP), as mandated by IDEA. Likewise, most colleges and universities in the United States provide reasonable accommodations through disability resource offices or centers. In addition, mandates exist for physically accessible buildings and classrooms, and the availability of other accommodations, such as Braille, electronic, or other alternate formats for textbooks, sign language interpreters, and personal lab assistants are well established. However, the existence and availability of these accommodations is not sufficient to ensure that students with disabilities receive them.

Teachers will often find that Universal Design for Learning (UDL) techniques assist students with disabilities as well as the student body as a whole. Instructors who may not be familiar with accommodations can seek out training to learn UDL pedagogical techniques, such as:

- **Tests:** Modifying tests and evaluation procedures to account for differences in abilities. For students who face barriers in communication, alternative assessment methods may be utilized. Students who struggle with writing, for example, may find it preferable to deliver an oral report or represent their answers pictorially or graphically. Instructor evaluations of group discussions are also an effective method of assessing

student learning.

- **Facilities:** Locating and providing accessible lab or design studio equipment where needed.
- **Documents:** Providing instructor-generated texts and classroom materials (such as websites, Microsoft Word, Microsoft PowerPoint, and PDF files) in accessible formats that include scalable fonts, captions for images and videos, and other features (Alston & Hampton, 2000, p. 162).

Melber and Brown (2008) offer additional recommendations:

- **Incorporate Objects and Specimens:** The introduction of objects and specimens contextualize the content of the classroom lesson. These engage the student more fully and allow them to become more involved with the learning process.
- **Plan for Durability:** Specimens incorporated into the classroom must be durable enough for rough treatment. Students with dexterity impairments may have trouble handling some objects, and students with behavior disorders may handle items roughly due to emotional stress or agitation.
- **Get out of the Classroom:** Adventuring outside the classroom to a museum, research site, or other informal learning environment enhances learning, especially for secondary and

postsecondary students. Learners with mobility impairments who may not be as able to travel to these places as frequently as their able-bodied peers may profit enormously from such activities. Such excursions should be a vital part of the curriculum. For students with disabilities, family finances or strict medical schedules may limit their ability to travel outside a traditional, controlled classroom setting. But when it is possible to do so, the educational benefit of such experiences is great.

In addition to specific accommodations or strategies, Scruggs and Mastropieri (2007) emphasize the importance of more general inclusiveness in science learning. Observation and interviews over a two-year period led them to posit several variables correlated with successful inclusive science classes. Of key importance were open, accepting classroom environments, administrative support, generally effective teaching skills, special education support, peer mediation, appropriate curricula (including those with a hands-on approach), and disability-specific teaching skills.

STEM DISCIPLINE-SPECIFIC ACCOMMODATIONS

Unfortunately, recommendations for accommodating

students with disabilities or developing UDL-based coursework are complicated, especially when considering more challenging and specialized classes at the high school level and progressing into college. What little research there is on the specific fields of science is quite uneven in its scope and depth. What follows is a brief summary of the progress that researchers have made in recent years.

Mathematics

Of the major STEM fields, mathematics is commonly identified in the literature as problematic for students with disabilities. Its visual nature, whether in terms of algebraic equations with complex notation or geometric concepts such as lines and angles, can render much of mathematics education inaccessible to students with visual impairments. Furthermore, generalized learning disabilities, which often affect the processing, memory, and organizational abilities so crucial to mathematics learning, can also pose barriers to students. Finally, mathematics is often subject to its own category of learning disability, sometimes referred to as dyscalculia. Just as dyslexia may pose barriers to literacy, dyscalculia may impede numeracy among STEM learners.

Underrepresentation of students with disabilities in mathematics is especially pronounced. Even more problematic is the fact that math is a key building block in many other fields within STEM. As such, it is pivotal that students whose disabilities may impede their ability to learn mathematics be accommodated as effectively as possible, in order to ensure their success in other fields. In a leading book-length study of mathematics disabilities, the editors draw distinctions between difficulty and disability in mathematical learning ability (Berch & Mazzocco, 2007). At the same time, however, they concede that precise definitions for mathematical learning disabilities have never been agreed upon, thus making it difficult to develop instruments and other measures for determining precisely those students who may experience this disability.

Processing abilities most commonly have been implicated in math-related learning disabilities, yet research in the field has been rather scant (Floyd, Evans, & McGrew, 2003). However, leading theories have generally pointed to spatial and executive functions as the leading determinants of math achievement, which led Osmon, Smerz, Braun, and Plambeck (2006) to undertake a study to better understand the role of processing abilities in math-related disability. Their findings provided

additional evidence for the role of spatial and executive functions as key components of processing-based math disabilities.

Furthermore, they concluded with the possibility that there might be subtypes of math disability, accentuating either of these two factors or manifesting as a combination of the two.

The increasing difficulty of mathematics courses in recent years, due in part to more rigorous graduation requirements and standardized tests, means that students are encountering pre-algebra and algebra courses earlier in the education process. As Algebra I has become more commonplace at the middle school level, the need for new ways to present content has been considered. This pedagogical need is especially pronounced in inclusive classrooms, where teachers encounter a range of learning abilities and styles (see, for example, Simpkins, Mastropieri, & Scruggs, 2009). In order to help educators select a curriculum and instructional approach to engage learners with both above average and below average math abilities, a number of approaches have been tried. Witzel (2005) has noted the possibility of embedding separate algebra programs, such as Algebra Tiles and Hands-On Equations, within the broader math program. Yet he has observed the challenges faced by district

administrators in trying to select the most appropriate programs and provide the necessary training.

Nevertheless, the fact that mathematics instruction has become more rigorous earlier in the curriculum has prompted the National Council of Teachers of Mathematics (NCTM), in its Principles and Standards for School Mathematics, to emphasize hands-on learning as a means to help bolster problem-solving and higher-order thinking skills of math learners. Yet, algebra's highly abstract nature can make such teaching methods difficult to implement. In some cases, it is challenging to locate suitable manipulatives to demonstrate effectively stepwise procedures in linear functions. Properly designed concrete objects (e.g., Algebra Tiles) can help overcome some of these problems.

Berch and Mazzocco (2007), in their efforts to understand the challenges that students face in learning mathematics, whether due to disability or non-specific difficulty, put forth a number of recommendations to address these issues. They are, in short: 1) begin teaching with real numbers and perform number comparisons, 2) encourage the use of oral language to describe numbers, 3) introduce formal symbols contextually so that students understand the need for them, 4) introduce concepts at the appropriate level and in a natural progression, and 5) allow

students to solve problems according to what is natural to them, and teach them other strategies, as well.

These proposed strategies are very much in line with the principles of UDL, and they may benefit all math learners. In particular, they address a number of observations made by Berch and Mazzocco (2007). Most prominently, they note that while basic reading proficiency is a strong predictor of mathematics achievement, number sense is an even stronger predictor. Toward these ends, the recommendations offered emphasize pedagogical approaches that will enhance students' numeracy and ensure that they are provided with the most solid foundation for dealing with numbers and mathematical notation. At the same time, however, the researchers recognize the pivotal role of oral and written communication skills in mathematics learning, especially where real-world problem solving is concerned. Hence, an emphasis on using real numbers and number comparisons is complemented by a recommendation to make language an essential component of mathematics instruction. Other recommendations underscore the fact that math education and knowledge building is cumulative in nature. Proficiency in advanced concepts is highly dependent upon mastery of more basic concepts and material. The suggestions offered by Berch and Mazzocco are meant to

ensure a logical and coherent sequence for teaching mathematics. In addition, mathematics education is frequently experiential in nature, in that students may learn the same concepts in different and perhaps individual ways. Hence, flexibility in the form of alternative ways of learning the material should be provided to maximize student success.

At the same time, there has been an increased emphasis placed upon the use of teaching approaches whose usefulness can be empirically validated. Mandates such as the reauthorized Elementary and Secondary Education Act, commonly referred to as the No Child Left Behind Act, have also driven calls for scientifically based interventions in mathematics instruction. In their study on mathematics instruction for students with learning disabilities, Maccini and Gagnon (2000) called attention to six categories that merited particular attention: a) advance organizers; b) direct instruction; c) technology and real-world problem solving; d) varied student grouping; e) graduated, sequenced instruction; and f) strategy instruction.

Advance organizers refer to the use of outlines or prompts to prepare students for a day's lesson. Generally, they are meant to bridge previous material and the current lesson, in order to facilitate improved knowledge-building. Allsopp (1999)

notes that an optimal advance organizer has three components: a) linking a current lesson to a previous lesson; b) identifying the skill or knowledge to be learned in the current lesson; and c) explaining the rationale for learning the skill. Presenting advance organizers in multiple formats, such as written on the board and orally, can further enhance their accessibility.

Direct instruction means a hands-on approach to pedagogy that ensures a teacher's sustained involvement during the process of learning, one that balances the delivery of content by the teacher with its understanding by students. Aspects of direct instruction involve a review of previously learned skills, teaching content through a number of techniques, monitoring of student performance and providing feedback, the use of corrective feedback, review, and re-teaching as needed, and a process of cumulative review. These techniques have been noted as particularly effective for students with emotional disturbance and learning disabilities, especially when cumulative reviews to ensure long-term learning benefits are emphasized (Maccini & Gagnon, 2000).

Technology and real-world problem solving address a growing emphasis on conceptual knowledge and its real-world application. This focus on higher-level problem solving is meant

to replace longtime approaches to math education rooted in worksheet-based drills, memorization and rote learning, and the routine manipulation of numbers in formulas. For example, the use of calculators, computers, or other similar technologies facilitates the movement of learning toward advanced concepts and moves students beyond their computational skills level. Proper use of these tools can also pave the way for more real-world problem solving.

Student grouping means the formation of small groups to enhance the learning process. In many cases, these groups involve peer tutoring to some extent, and this approach may be useful in classrooms where a wide range of student abilities are represented. Hence, peer-mediated instruction furthers the goals of inclusivity in mathematics education through reciprocal tutor and tutee roles and teamwork in learning.

Graduated instructional sequence provides a systematic approach to instruction that helps students as the material they learn becomes more complex, progressing from concept development to skill acquisition. The method involves three phases: a) concrete learning, or the use of objects to represent a given concept, b) semi-concrete, drawing pictures of the aforementioned objects, and c) abstract, the use of numerical

representations in teaching concepts (see also, Maccini & Ruhl, 2000). As aforementioned authors such as Witzel (2005) have noted, this method has particular utility for students with learning disabilities. Secondary-level students with these disabilities frequently encounter challenges with problem solving tasks, and they commonly perform at lower levels as a result, even at fifth-grade level or below. The graduated instructional sequence can be useful in addressing a number of concerns, including selection of proper operations for solving a problem, differentiating between necessary and extraneous information in word problems, and actively participating in problem solving tasks. These same issues often pose problems for students who may have difficulty, but not necessarily disability, in learning mathematics. Hence, graduated, sequenced instruction may have benefits for many learners.

Strategy instruction refers to those techniques to help learners comprehend, organize, and remember the vast amounts of material that may be taught in the secondary mathematics classroom, all while aiding students to become more independent and active learners of this content.

In addition to the six strategies proposed by Maccini and Gagnon, Witzel and Riccomini (2007) have proposed the OPTIMIZE strategy to assist mathematics teachers to organize their curricula

by designing adequate and appropriate modifications to increase the achievement for all students, including those with disabilities. Congruous with UDL principles, the OPTIMIZE strategy helps teachers address any potential gaps or need for supplemental instruction:

- O:** Order the math skills of a textbook chapter before teaching.
- P:** Pair your sequence with that of the textbook
- T:** Take note of the commonalities and differences
- I:** Inspect earlier chapters to see if they cover the differences. Check later chapters to see if they cover the differences.
- M:** Match supplemental guides to see if they cover the differences.
- I:** Identify additional instruction to complement the current test or curriculum.
- Z:** Zero in on the optimal sequence with your new knowledge.
- E:** Evaluate and improve the sequence every year (Witzel & Riccomini, 2007, p. 15.)

The OPTIMIZE strategy attempts to apply paradigms of reductionism and constructivism to inclusive mathematics instruction. Reductionism refers to “reducing instructional goals to a series of specific and sequenced math skills,” while constructivism focuses on “designing student-centered lessons as a means for students to create their own knowledge” (Witzel & Riccomini, 2007, p. 15). In doing so, teachers can think proactively about effective and efficient lesson sequences, model and guide students through effective materials, and especially, monitor learning to modify and accommodate students who may require remediation or enrichment.

Despite the emphasis placed on accommodating students with learning disabilities, other disabilities deserve consideration in mathematics education. Of particular note are students who are blind or have visual impairments. For these learners, the orientation and mobility (O&M) approach may be helpful. Smith (2006) discusses the applicability of O&M, a technique for assisting individuals who are blind or have visual impairments to travel safely through their environment, for mathematics (See table on page 132). For example, geometry terms concepts—including “*parallel*,” “*perpendicular*,” “*point*,” “*line*,” “*rectangle*,” and “*curve*”—are frequently used in conventional O&M training and may be

adapted for mathematics instruction. Abstract concepts such as a point—here, a fixed position in space to help students understand their position in the environment—can be used to teach more complex concepts such as “*line*”—the connection that ties points together. Also, terms such as “*parallel*” and “*perpendicular*” are commonly used in O&M instruction and may be adapted for math pedagogy. Students may conceptualize how a street with cars runs parallel to the sidewalk on which they are walking, or that intersections in the real world are examples of perpendiculars. Hence, students with visual impairments may be able to conceptualize a geometry classroom discussion from their real-world O&M experiences.

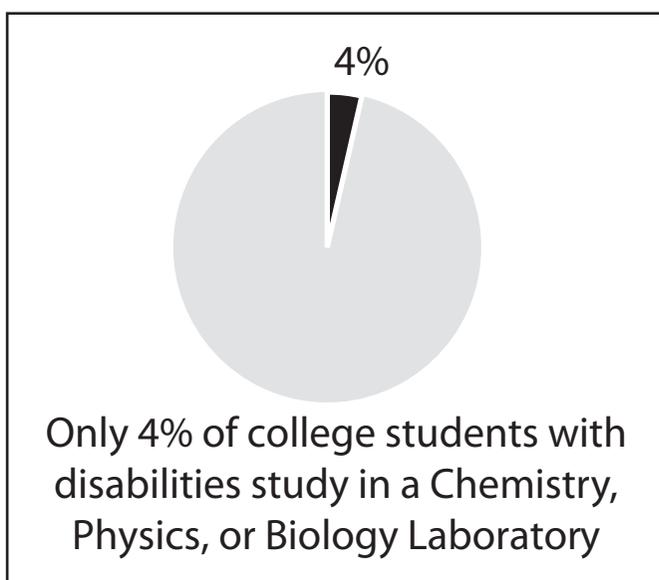
Mathematical Concept	Orientation and mobility connection
Linear Measurement Concept Development (e.g., length, width) Time/distance estimation Distance formulas	Develop measurement by learning distances through walking differing lengths. Provide opportunities for students to estimate distance through route travel and planning. Real-world application of distance equals time times rate ($d=rt$).
Definition of geometric terms Points Line Segments	Use fixed positions in space, such as landmarks, to explain points.
Positional terms (e.g., above, below, under) Plane	Introduce and use these terms throughout instruction.
Angles	Turns of 45° , 90° , and 180° are commonly used in travel.
Polygons	Explore squares, rectangles, and circles in travel, such as around city blocks or around parks. Introduce other polygons, such as pentagons, hexagons, octagons by exploring traffic signs.
Parallel lines	Explore this concept through shorelining and parallel traffic.
Perpendicular lines	Demonstrate this concept by crossing intersections of sidewalks, hallways, and streets.
Consumer Math Skills Counting Money Skills	Various situations such as counting doors, steps, or streets provide counting opportunities. Business (or semi-business) settings provide opportunities to expand money skills.
Perimeter	Explore this concept during perimeter familiarization of a room or while traveling around a city block.
Area	Explore this concept during familiarization (or exploration) of any area (a desk, table, or room) using the grid pattern.

(Source: Smith, 2006)

Laboratory Science Accommodations

A wide range of simple accommodations have emerged in recent years to assist students with disabilities in the chemistry, physics, or biology laboratory. At the college level, these students make up about four percent of all college students with disabilities (NCES, 2009) (See Figure 3.2).

Figure 3.2



Classroom accommodations are typical for the STEM fields, but the heavy reliance in physics on advanced mathematics makes it necessary for students to be provided with accessible math tools such as rich text descriptions and accessible software for generating characters and symbols.

Laboratory accommodations are varied, but in general, students with mobility limitations need accessible workplaces and, frequently, wheelchair-height work surfaces. Students with visual limitations should be given opportunities to learn the layout of the lab. Adding Braille labels to laboratory equipment or creating raised-line pictures and diagrams increases accessibility for students with visual impairments. Syringes and other pieces of adapted equipment are available with tactile, notched graduations or Braille markings, and these may further assist in accommodating learners with limited visual function. Raised line drawings can assist these students in understanding the content of images, charts, and graphs, and software is available that detects color changes, which is useful in standard procedures such as titrations. Other instruments are available to audibly announce measurements, helpful for students with either visual or dexterity issues. Magnetic, Braille-labeled cut-outs on whiteboards are simple modifications that allow the students with visual impairments to represent electron configurations in a tactile format that can easily be visually interpreted by instructors. It is also possible to create tactile Lewis dot structures and Aufbau diagrams (Supalo et al., 2008).

Physical Science Labs: Representative Examples

A few case studies derived from published university lab manuals may serve as representative examples of the kinds of accommodations that are often needed. In the lab manual for a typical physics course, students are asked to make a number of pre-determined drawings and graphs using a ruler and pencils, as well as use a personal calculator. Students are expected to “write-up” lab findings in-class using paper and pencil. Clearly, students with disabilities may not be able to fulfill these expectations in precisely the same way as others. Accommodations for these exercises could include allowing the use of computer-based software relevant to a given student’s needs, such as speech-to-text dictation (for dexterity limitations) or text-to-speech (for vision impairments or LD). Where students are expected to create and fill data into forms, accessible electronic documents should be provided for them. If an exercise’s objective involves proper design of a table, students may be assigned a helper to allow them to orally dictate the form design, if possible. Where students are expected to show the mathematical processes they used to calculate results, instructors should ensure that this can be done via accessible electronic documents, such as an accessible Microsoft Word format. Drawing of detailed graphs on ruled

paper poses serious barriers for students with vision and dexterity limitations. In some cases, students could dictate the data to an assistant, while concepts of properly “smoothing” graphs could be demonstrated to students with vision impairments using tactile models.

Image- and text-based background materials or textbook information related to particular experiments must be provided in accessible formats. Depending on the student, this might include providing commercially available e-textbooks, as well as making instructor-generated slides and handouts available online or in an alternate, accessible format. In particular, images may require detailed text descriptions, haptic models, or both.

Actual lab experiments vary so widely that it is difficult to provide representative examples. For instance, one introductory astronomy experiment involves the observation of differences in the appearance of planets in the solar system over a period of time. The experiment demonstrates methods such as planetary shading (e.g. a full moon versus a crescent moon) to determine orbital position relative to the sun, other planets, and the observer. Such an experiment assumes that the student has strong visual skills, as well as the capability of making direct visual observations. In such a case, a combination of commercially available physical

models and detailed text descriptions might be enough to substitute for direct observation for a low-vision or blind student (Benacchio, 2001).

Numerous experiments in a typical introductory physics course require students to handle, assemble, and manipulate experimental apparatuses. In one university course with a demonstration of Newtonian physics, students launch a small glider from a metal track using a hanging weight. Optical sensors built into the track measure acceleration, and students record and analyze experimental data using lab-based personal computers running software developed by the university. The lab setup could present substantial obstacles to students with disabilities. Students with vision or dexterity impairments and wheelchair users may not be able to set up the apparatus without assistance. Software accessibility might pose a major problem unless the software worked well with a screen reader, and it may be preferable for the software to be installed on a student's own computer that already contains accommodation software (Fichten et al., 2009).

Biological Science Labs: Representative Examples

As with the physical sciences, the multitude of course

offerings and lab exercises in the biological sciences make it difficult to offer generalized accommodations options. However, the following cases are presented as typical. Many biological science labs begin with a lab manual and a lecture. Appropriate accommodations for these aspects of learning could include use of computer-based software for speech-to-text dictation, text to speech, the use of alternate input devices, etc. A sample high school biology laboratory manual's first exercise begins with a discussion of lab safety and lab equipment. At the end of the unit, students are asked to identify in writing the meaning of a series of safety symbols, or draw and describe the use of a series of instruments (Fraser, 2008). Students also learn how to draw line and bar graphs using pencils and paper. Students with vision and dexterity limitations will need to be provided with alternatives for these vision-based or dexterity dependent activities. Assistants might be employed to create graphs or charts based on input from the student with a disability. Making drawings of any kind or identifying symbols that can only be presented visually may prove to be an insurmountable problem, but graphics software may assist some students. For students with severe vision impairments, a possible solution to the identification would be to adhere to good UDL practice and revise the exercise so that, for example,

students identify and explain images rather than draw them. Accessible electronic images with descriptive text tags might be designed that would allow a screen reader to detect the name of the device to be identified without giving the student too much information.

In a unit on the scientific method from the same high school level lab manual, the stated goals of the exercise include developing the ability to observe and record data. Students are asked to visually observe various specimens surrounding them in the classroom and describe them. It is assumed that there are organisms such as insects, fish, worms, mice, etc., in the room at the time. This exercise presents barriers to students with certain disabilities, especially if the plants, animals, or insects cannot be handled, or if they are too delicate to be handled relatively roughly. Tactile models might enhance the exhibit of the living organisms. Displays of these organisms must be arranged so that students with mobility impairments can access them, and organisms whose interesting characteristics depend on particularly human sensory interpretations (smell, color, sound) may present major obstacles. To make such an exercise accessible, it should be universally designed, and perhaps further adjusted

each time the class is offered to accommodate for particular students with disabilities who may be present (Fraser, 2008).

In one of the sophomore or junior-level university ecology lab manuals audited for this study, students are divided into groups of three to four. They select a 100 sq. meter region within a large forested area and design a “data sheet” for manually writing field-gathered data. Areas to be observed are marked off with a stake driven into the ground, and the boundaries are determined by physical measurement relative to that stake. Within the observational area, students make approximate measurements of shrubs and trees, identify their species, count them, and evaluate their proximity to other trees and plants. Students then transfer this data to an Excel spreadsheet and manipulate it using equations supplied by the lab manual. A later assignment requires a library and/or online research component, a field data collection and data analysis component, and a dissemination or education component. Depending on which track students choose, they may be required to produce an 8-10 page project paper or report their results in a formal, oral presentation. Again, many of these activities are typical of the kinds of things science lab instructors ask of their students, and many of them are inaccessible to students with disabilities.

Fieldwork can present considerable barriers to students with mobility and vision impairments. One alternative in this case might be for the instructor to guide students with mobility impairments toward a plot of forest that is most easily accessible despite the fact that such a selection may alter an important part of the assignment, which is the selection of a random area. Another solution might be to find a team member or assistant to help the student with mobility issues. However, other aspects of the assignment such as physically measuring plants and trees will not be fully addressed with this solution. Students with vision, mobility, dexterity and certain learning disabilities may have trouble fulfilling the requirement for field-generated data recorded on paper, and with subsequent processing of this data on particular software programs such as Microsoft Excel as specified by lab manuals. Giving students flexibility to use other means of dealing with data, or using their own software if they prefer, would be an acceptable approach to this problem. In this instance, the laboratory manual recommends that students rotate tasks such as data-gathering and data recording, and instructors may be tempted to tell students with disabilities simply to avoid doing the tasks for which they feel they are unsuited. However, this runs counter to one of the stated goals of field/lab exercises,

which is to immerse each student in the physical work of science. Ultimately, this contradiction between goals and accommodation may be worked out through the further development of UDL practices specific to lab and fieldwork situations.

ACCOMMODATIONS FOR ENGINEERING AND TECHNOLOGY EDUCATION

Engineering is a very diverse field, making it almost impossible to generalize about accommodations for engineering students with disabilities. The field's major specialties, mechanical, electrical, chemical, civil, aerospace, and biological engineering, each represent distinct challenges. One key difference between engineering and other fields of STEM education is that engineering-focused courses are typically not offered in high schools, and even within the typical four-year program, classes labeled "engineering" generally are offered to students only after they reach the sophomore level. So while there may be a basic-level "introduction to engineering" course offered to freshman, students in virtually every engineering program in the U.S. actually study mathematics and basic science during the freshman and most of the sophomore years.

A commonality across most fields of engineering is that while much instruction takes place in a classroom, engineering educators tend to consider the “meat” of the curriculum to be laboratory and/or field work. The engineering laboratory class typically combines theoretical background training, mathematical analysis, and the setup and operation of complex pieces of equipment. This style of education is arguably more “hands-on” than comparable science laboratory work, particularly in terms of how much it is valued. The transition from the STEM lecture course and the basic-science lab to this engineering style of education is a critical juncture for all students, most notably those with functional limitations.

Examples of Engineering Accommodations

The literature on engineering-specific accommodations is very limited. It is fair to assume that accommodations for lower-level students will be identical or nearly identical to those for regular science and math students. Thus physical accommodations of the kind regularly provided by on-campus disability support offices will pertain here, such as the provision of accessible buildings and classrooms, ensuring Braille or electronic versions of textbooks are provided, and offering students the

possibility of note takers, sign language interpreters, or personal lab assistants.

Professors teaching both lower and upper-level courses can modify their teaching methods with UDL techniques that benefit all students, including:

- Having training in recognizing and accommodating students with disabilities
- Modifying test and evaluation procedures to account for differences in abilities
- Providing accessible lab or design studio equipment where practical
- Providing reading and classroom materials (such as Web sites, Word, PowerPoint, and PDF files) in accessible formats that include scalable fonts, captions for images and videos, and other features (adapted from Alston & Hampton, 2000, p. 162).

These general accommodations can be carried over into advanced-level courses and laboratory settings, but they must be supplemented. There is virtually no literature covering the vast majority of engineering education settings. The following serve as hypothetical case studies of possible accommodations. They are drawn from recent undergraduate laboratory guides at various

universities, and were chosen to illustrate the different types of situations encountered in various fields of engineering.

Civil Engineering Example

An introductory course in many CE programs is solid mechanics, including static and dynamic analysis. Much of the instruction for this type of course relies on lectures and demonstrations, with students employing techniques such as mathematical and vector analysis to complete their assignments. UDL instructional approaches that make textbooks, lectures, Web pages, and class handouts accessible would adequately accommodate many people with disabilities, though the graphical nature of the content does make the task rather difficult. Exercises in vector analysis rely heavily on mathematical symbols encountered in other fields, as well as unique graphical conventions and symbols. Students may be asked to analyze or create three-dimensional drawings. Software exists to enlarge such equations (if they are in the appropriate electronic format) and simplify the drawing or keyboarding of symbols, so many students with low-vision or dexterity impairments may be adequately served. Students with total blindness, however, will face additional difficulties. Some mathematical symbols that are

common to many fields can be interpreted by a screen reader or a Braille display, but some graphical elements unique to vector analysis may not currently be made accessible using existing tools.

Mechanical Engineering Example

Undergraduate ME curricula somewhat resemble the typical civil engineering program, but diverge following an introductory set of courses. In a combination lecture/laboratory course in mechanical engineering, a student with disabilities will encounter the need for accessible texts and universally designed classroom presentations and web-distributed materials. In the laboratory, students use scale models and specialized laboratory equipment to learn about fluid and solid mechanics, vibration, heat transfer and other related phenomena. An example of a typical laboratory exercise might be an experiment to measure and analyze the effects of vibration in a small structure. Laboratory hand-outs explaining the purpose of the experiment and providing instructions for the experimental setup contain text, graphics, and mathematical formulae, meaning that students with vision impairments or learning disabilities may need universally designed versions of them. The experimental setup might consist of a scale model of a structure, a source of mechanical vibrations, vibration sensors, and electronic equipment to analyze and

display information about the effects of vibration on the structure. Use of measuring instruments may present obstacles for students with dexterity, visual, and perhaps hearing disabilities. As in other examples presented here, the typical accommodation would be to provide helpers or, if students work in teams, to assign duties based on ability.

Electrical Engineering Example

Both lecture and laboratory courses in EE involve the extensive use of mathematics equations, and today they are usually manipulated using computer software. Just as in other fields of engineering, mathematical work for electrical engineering is supported to a point by accessibility software. Additional difficulties arise when, for example, students are asked to draw and label circuit diagrams on tests or lab worksheets. These drawings are based on graphical conventions consisting of standardized circuit elements, connected by lines, arrows and other symbols that vary from drawing to drawing. Students with dexterity impairments or low vision may have trouble creating such drawings, and software is not generally available to make the task easier. Students with vision impairments may also be unable to rely on visually based lexicons of standard symbols. Further,

such exercises are often accompanied by laboratory experiments using measuring devices, electrical power supplies, electronic components, wires, probes, and the like. Few of these pieces of equipment are generally available in an accessible form, making their manipulation difficult or impossible for students with many types of disability, and requiring the use of helpers.

Chemical Engineering Example

Chemical engineering distinguishes itself from the science of chemistry largely by emphasizing the industrial production of chemicals rather than the study of natural chemical processes. Instruction in this field extends scientific chemistry's beakers, Bunsen burners, and measuring instruments to include an understanding of the processes and equipment used to make chemical materials. Providing basic accommodations, such as accessible work stations, classroom materials and lab manuals, is nearly the same as in other fields. Minor lab equipment accommodations may be the same as those provided in introductory chemistry, such as test tube holders and burners with paddle-type knobs for users with dexterity limitations. The nomenclature of chemical engineering is similar to that in higher mathematics, so students with vision disabilities

should be able to use accessible textbooks and screen readers. Laboratory experiments, however, pose additional problems. For example, one typical experiment involves small teams of students calibrating and using a system called a catalytic reactor, in which a flow of methane gas through a catalyst results in conversion of the gas to water and carbon dioxide. Students are expected to operate knobs on the machine and view numerical displays to establish gas flows, ensure that a gas chromatograph is accurately measuring the reaction products, and then operate a specialized printer to convert the output of the chromatograph into a printed chart. None of this equipment is accessible as supplied, and it presents barriers for students with visual impairments (numerical displays, printed charts), dexterity impairments (fine-tuning knobs, entering data on keypads), and possibly mobility impairments (the equipment is physically large and cannot be operated from a seated position). As in other cases, the immediately practical accommodations would be to ensure that other members of the team could be solely responsible for the inaccessible aspects of the experiment.

CHAPTER 4

DEBATES, RESEARCH GAPS, AND FUTURE DIRECTIONS

INTRODUCTION

The overall pattern revealed by the literature in this field is a basic division between inclusive teaching/universal design for students in general, versus specific accommodations (technical or pedagogical) made for individual students with disabilities. The two intersect at the K-12 level as part of recent trends toward inclusive teaching or “mainstreaming,” where emphasis has been placed on educating students with disabilities in the general STEM classroom, rather than special education classrooms. However, they may still receive accommodations as part of an individualized education plan (IEP). In such situations, proponents of UDL also emphasize inclusive teaching techniques that benefit all students, including these students with disabilities.

The UDL concept is the philosophical foundation for inclusive teaching, and the literature demonstrates that many inclusive strategies are effective. Orr and Hammig’s (2009) survey of pedagogical techniques found that in 21 of 38 studies, inclusive techniques and learner supports were in use. These studies

provide evidence for the efficacy of some of these techniques in the accommodation of students with disabilities. Nevertheless, there is room for further inquiry. Despite its increasing deployment in K-12 education, UDL is not as widely implemented in postsecondary education. The following sections discuss opportunities for further research in several of the major areas of UDL/inclusive teaching, followed by a discussion of research gaps in the field of technical accommodations. Finally, observations on some STEM-specific issues that pertain only to college-level and graduate-level education are offered.

UDL APPROACHES

Multiple Means of Presentation

As one of the hallmarks of UDL approaches, the use of multiple means of presentation has long been established as one of the most efficacious methods for accommodating students with disabilities and ensuring inclusive learning for all students. Supporting research for using multiple formats to convey course content, especially for the benefit of students with learning disabilities, is relatively robust (Orr & Hammig, 2009; Fuller et al., 2004; Fichten et al., 2009). The efficacy of the approach in STEM

learning is treated by Kitz & Thorpe (1995), Brothen and Wambach (2003), and Sullivan (2005).

Given the relatively well-established use of this technique, subsequent research should focus on refining its use in the classroom and expanding its use into situations where it has not yet succeeded. One area of concern involves determining its optimal use. Non-critical, ubiquitous adoption that fails to take into account the specificity of a given course or classroom setting actually may be detrimental. The use of lectures, traditional readings, and electronic materials to convey the same course content may increase accessibility for learners with sensory impairments who may have difficulty accessing one of these forms. Yet questions remain about whether such methods benefit people with other disabilities. For example, research based in dual coding theory (Beacham & Alty, 2006; see also, Orr & Hammig, 2009) has suggested that course content delivered simultaneously in multiple formats (i.e. text and images or diagrams and sound) might place an undue cognitive load on students with dyslexia and actually inhibit learning. In summary, future research might focus on the optimal prescription of multiple means and refining its use, with an emphasis on how specific disabilities are impacted by its application. Researchers also need to push further to

examine postsecondary education beyond the freshman level and, if possible, post-graduate instruction.

Learner/Lecture Supports

In the area of lectures, a number of studies have pointed to the use of lecture supports such as guided notes to improve student learning. Most of these studies relied on student reporting of outcomes, but some studies have employed a more rigorous approach to determine their impact. Among these was an early case study design employed by Lazarus (1993) and a more recent investigation by Ruhl and Suritsky (1995) that compared the use of outlines with the “pause procedure.” Both of these studies confirmed the efficacy of outlines in improving student learning, and the latter suggested that other methods might be even more effective. Here, this finding has presented two research needs. First, there is a continuing need for rigorous studies that go beyond self-reporting to augment these classic studies and more definitively explicate the effectiveness of lecture supports. Second, there is a need for studies to determine whether outlines, in and of themselves, might actually interfere with student note-taking abilities. While outlines might function as a support, questions

persist as to whether they impede the usefulness of other interventions directed at students with LD (Orr & Hammig, 2009).

Backward Design

Backward design, a pedagogical method that involves structuring teaching and assessment around desired learning goals and objectives, represents a relatively new approach in UDL. Only 4 of the 38 studies referenced by Orr and Hammig (2009) addressed this theme. Research on the usefulness of this method for students with disabilities has been conducted via surveys (Hill, 1995), focus groups (Madaus, Scott, & McGuire, 2003), and case studies (Brothen & Wambach, 2003; Sullivan, 2005), all of which suggest the approach's potential. However, it must also be noted that this approach is still emerging. While initial findings are promising, more research needs to be conducted in order to ground these nascent investigations and better establish causal relationships between the utilization of backward design and improved academic performance by students with disabilities.

Architecture

Universal design emerged from the field of architecture and industrial design, though its translation for use in the field of education and elsewhere has obscured its origins. The irony

of this is that physical facilities for STEM education, particularly at the university level, may be of fundamental importance in research and teaching, and may present unique problems for advocates of universal design. While basic UD architectural features such as physical access to buildings and classrooms have been widely, if not optimally, implemented, deeper issues remain for designing campuses, structures, and facilities with UDL as a planned goal rather than an afterthought, compromise, or specific accommodation. Architecture has remained outside the scope of this literature search, which focuses on the education literature, but must be incorporated into future studies, particularly those examining higher education. Not only are facilities on most college campuses geographically dispersed, the scope and range of educational situations in STEM education is much more diverse than at primary and secondary educational levels.

ACCOMMODATIONS-BASED APPROACHES

In both general education and STEM-specific classrooms, the most widely used approach is the traditional one of providing specific accommodations to individuals with disabilities on a case-by-case basis. It is arguably the most practical short-term solution for many situations. The types of accommodations available to

STEM teachers can be roughly divided into those that involve considerable human intervention (ASL interpreters, note takers, laboratory assistants, etc.) versus technical accommodations (accessible laboratory workstations, screen readers, “talking” lab instruments, etc.). The relative scarcity of recent literature on the human intervention side suggests that it is considered non-controversial, or at least it apparently no longer makes for an interesting research topic. Questions remain, however, as to the efficacy of human interventions versus technical solutions, or indeed the whole question of whether technology such as distance education or e-learning could be more effective than any type of traditional classroom for students with certain disabilities, particularly at the college level where students are expected to learn more independently.

In the area of technological accommodations or assistive technology, many researchers in the STEM education field seem focused on very specific accommodations, but a few share a broader perspective that encompasses both the technological “fixes” and the environment in which they are deployed. Thurlow (2002) notes that an influx of research funding starting around 2000 led to an increased number of studies on accommodations at the primary and secondary levels, but that these studies

were oriented toward the states' need to monitor their students' performance in standardized tests, and notes that the use of these accommodations in everyday instruction is lacking.

Edyburn (2000) in particular has considered the institutional supports for assistive technology, and has produced a list that (while not focused solely on STEM) is useful in suggesting where the major gaps in our knowledge exist:

- How many certified assistive technology specialists are employed full-time in public schools?
- What is the composition of assistive technology teams in public schools?
- What is the caseload of an AT team?
- Do all students who could potentially benefit from assistive technology have access to appropriate devices and services?
- How long does it take to assess the need for assistive technology, acquire devices, train, and implement?
- What is the quality of assistive technology services?
- What impact does the use of assistive technology have on the academic performance of its users?

In a similar vein, Ofiesh (2007) writes that while, for example, recordings and text-to-speech devices are routinely supplied

to students with learning disabilities who have trouble reading, “there is no research at this time to help disability services personnel make decisions about who would be most likely to benefit from these accommodations, and under what circumstances” (Ofiesh, 2007, p. 242).

Human-based Accommodations

There is still significant work to be done if skilled human assistants are to be effective in STEM education. A major obstacle to human-based accommodations such as note takers for students with dexterity problems, or sign language interpreters for deaf students, is that they encounter obstacles in STEM courses that demand of them additional specialized skills. Sign language interpreters, for example, will have to contend with a large vocabulary of unfamiliar technical terms, engineering abbreviations and symbols, and other field-specific language in order to adequately serve deaf students across multiple STEM disciplines.

The use of assistants also runs counter to the culture of STEM education, predominant in higher education, that treats “hands-on” participation as one of its most sacred tenets. Means of accommodation that rely on skilled assistants all skirt the issue

of the visceral aspects of science and engineering, and promote what might be called “partial participation.” These include assigning helpers to do laboratory work as the student with a disability merely observes. The more current alternative, having students with disabilities work in groups with non-disabled students and dividing the labor according to ability, is sometimes considered to be a rationalization for partial participation. Future researchers in this area may need to look for better ways to integrate their approaches with the culture of education peculiar to STEM fields.

Technology-based Accommodations

It seems clear that assistive technology seems to be moving in a direction that shifts more of the burden for specifying equipment, learning to use it, and actually employing it in an educational situation onto the student/user. That is not necessarily a negative attribute, particularly in the case of universally designed technologies.

In the UDL context, technical accommodations for specific students with disabilities are subsumed under the goal of making education accessible to all, making it difficult to evaluate them in isolation. Making online documents accessible, for example, might

be considered as merely an accommodation for blind students, yet the same accommodation when incorporated into a UDL strategy to improve access for all students is partly a technical “fix” and partly a “human” intervention in the form of altered pedagogy. UDL is developing as an encompassing teaching philosophy consisting of specific technical accommodations chosen for their relevance across multiple disabilities. It seems likely that future research can and should be aimed at finding technical accommodations best suited to the UDL approach and demonstrating how they can be incorporated into it.

This trend is particularly evident in the wedding of computer intelligence with the physical aspects of STEM education, ranging from buildings and classrooms to lab equipment. The list of accessible, specialized lab equipment is large and growing. A small portion of it is merely traditional equipment adapted for users with disabilities, such as tools with easily grasped handles for people with dexterity difficulties. A faster-moving group of accommodations involves equipment that integrates digital electronics to “translate” measurements and actions into some form that is accessible to users with disabilities. Yet only in the past few years have researchers begun

to investigate the expansion of the accessibility of these “smart” tools through the use of computers and IT.

Colwell, Scanlon and Cooper (2002), for example, has proposed a promising set of laboratory tools that can be used or in some cases manipulated over the Internet. Research is ongoing in the field of augmented reality systems, currently undergoing testing in many universities for classroom or lab use, which are, according to one study, fairly well-adapted for some students with disabilities (Arvanitis et al., 2009, pp. 247-8). The European Commission has also sponsored the development of a remote laboratory, accessed via the Web, which is designed so that it can be used with computer-based assistive technology. More established (and also more accessible to students with vision impairments) are haptic visualization models, which typically translate visual data into some form that can be felt or heard. For example, Kenneth Barner’s team at the University of Delaware developed a way to digitally process images from a microscope and translate them into tactile form (Barner, Foulds, Way, & Fritz, 1997).

Colwell et al. (2002) recognizes that IT or virtual-reality based simulations of the laboratory experience have shortcomings that ultimately may rely on additional interventions

in order to work effectively, but still the approach may be a harbinger of future research. Much high-level work remains to be done in this field simply to prepare the way for future technologies. For example there is as yet no communication standard for remotely-operated or remotely sensed laboratory instruments, and history shows that standards-setting is a crucial element in the success of new IT technologies. It is also unclear whether the limitations of computer-based technology will ultimately prevent current types of laboratory work from ever being adequately accessible, or whether laboratory and design studio curricula would have to be redesigned to be universally accessible using technology.

UNADDRESSED ISSUES

There are numerous major gaps in the research on STEM accommodations, several of which relate only to the university level. This weakness is possibly a result of the fact that in order to gain entry into universities in the first place, most students with disabilities have faced significant obstacles at the lower levels. However, partly as a result of public school “mainstreaming,” as well as the wider recognition of so-called milder disabilities such as dyslexia and ADHD, the number of students with disabilities

in universities is growing. There is also speculation that the faster pace of learning at the university level reveals previously undiagnosed learning disabilities in many students, but this research has been conducted only on a limited scale (Rosebraugh, 2000). Research on the special problems related to university level STEM education must begin to explore new areas. With limited data available, the following comments are intended to be a speculative basis for future discussion.

One broad conclusion that this literature review has demonstrated is the dearth of research on UDL and accommodations as they apply to the university setting. A 2007 study by Soukup, Wehmeyer, Bashinski, and Bovaird noted that the results of the implementation of accommodations mandated by the IDEA legislation of 1997 is not yet well studied and that the outcomes for those students who progress (or fail to) into college is also virtually unknown. One of the goals of the IDEA legislation is to promote student “engagement” rather than merely accommodation. Several studies have demonstrated that at the primary level, students with severe disabilities are still qualitatively less engaged in the main activities in a classroom than are students with mild or no functional limitation. But there has been little follow up at the university level, where the nature of student

engagement changes tremendously and often depends much more heavily on self-realization. Studies of younger children also suggest that careful manipulation of the groupings of children in classrooms has strong effects on engagement. Again, the implications for college students are still unknown, even though in a postsecondary setting they are faced with numerous new and often self-chosen options for groupings, such as lab partners, informal study groups, fraternities and sororities, etc. (Soukup et al., pp. 104, 108).

Also largely unstudied are ways to generate faculty “buy in” for UDL, given the highly individualistic culture of college faculty. Clearly, ADA-mandated equal access to education is universally recognized in U.S. colleges and universities, but what constitutes a reasonable accommodation, one that does not fundamentally alter a course or lower academic standards, is a gray area (Acker, Gray, & Jalali, 2009). One traditional approach to college teaching has been to immerse the student in the academic atmosphere of the lecture, the laboratory, and the research library without much explicit attention to pedagogy. Indeed, it is widely assumed that part of what constitutes academic ability at the university level is the ability for self-guided learning and independent inquiry. UDL encroaches on this hoary tradition, and while that may explain

why it has not immediately caught on in STEM education, it does not mean that UDL advocates should not study ways to change that situation.

University Level Student Research

Student research holds a central place in the education of graduate students, and increasingly since the late 1990s, the incorporation of undergraduates into the research process has taken hold in U.S. universities. In all universities, research takes place in libraries where physical access for people with disabilities has long been given attention and has been addressed (albeit imperfectly). Since the 1990s, much more research of all kinds takes place on the Internet, where numerous hardware and software accommodations are available and fairly well implemented. But the inclusion of people with disabilities in research for STEM education at the university level demands much more than this type of standardized, campus-wide accommodation. Fundamental questions remain, such as how to make STEM universally accessible once students move into original research. In a science laboratory conducting original research, for example, experiments are by definition unique to the scientific question under examination, as opposed to the

types of standard exercises that introductory or secondary level students conduct to learn the scientific method. Complicating the matter is the growing adoption of inquiry-based STEM education, where students design their own experiments and experiences. Theoretically, then, there may be no practical way to make the research laboratory universally accessible using the “specific accommodation” approach, which leaves a UDL approach as the best option. However, this question has not yet been explored in the literature, and it is not clear how that research agenda should be launched.

Graduate and Professional Education

While graduate and professional education is arguably one of the major driving forces behind university level STEM research and teaching, the literature on graduate students with disabilities – inside or outside the realm of STEM – is quite small (exceptions include Runyan, 1991 and Rosebraugh, 2000). No innovation, pedagogical theory, or UDL approach mentioned in this review adequately studies graduate students with disabilities. A parallel could be drawn from the sociological and historical fields studying women and minorities. A steadfast recommendation for increasing the number of women and minorities in to

engineering, for example, has been the urgent need for role models and mentors. That in itself should be enough to warrant scrutiny of the way in which students with disabilities are brought into graduate education and nurtured through master's degrees and PhDs. Sadly, that is not the case, and it is a glaring omission on the part of disability and education researchers.

The Problems of Team-based and “Hands-On” Education in STEM

In addition to the STEM-specific accommodations mentioned above, there are issues related to science and particularly engineering and architectural education that are almost wholly absent in the literature. The problems presented by the team-based approach, especially in laboratory and project work, and the strong culture of visceral or “hands-on” learning have been mentioned several times in the sections above. Yet the fact that the culture of science and engineering education so ardently emphasizes the value of “hands-on” laboratory or experimental experience makes it curious that the literature on addressing cultural change is so weak.

This unique culture of physicality is a major issue in engineering. Traditionally, all engineering students have been

required to complete extensive hands-on training that is beyond the requirements even of laboratory science. This tradition is deeply ingrained in engineering pedagogy and has been since the 19th century, when students were trained in machine tool operation, the use of mechanical and electrical instruments, and gained experience in factory-like laboratories pouring iron, building electric motors, etc. Students often built working scale models of experimental equipment (McMath et al., 1985).

That said, the definition of “hands on” education has changed since the introduction of computers. Computers have substituted for STEM educational activities that previously were accomplished with pen and paper (i.e. design), or with physical models (through the use of “simulation”). While the existing literature extensively addresses computer use for general instructional activities (such as taking notes or producing documents), researchers have only just begun to explore the vast realm of scientific computing and its accessibility.

Universities, meanwhile, have made scientific computing ubiquitous in STEM education. The widespread adoption of personal computers in place of actual hands-on experience was noted by the late 1990s, as the price of powerful computers dropped to a level at which virtually any university student could

afford one, and in fact many engineering programs supplied them to the students for “free” (paid for by tuition and fees) and required their use. The results of all this computerization have in some cases taken encouraging turns toward greater accessibility, seemingly by accident. Some institutions in the 1990s actually described their aspirations to make simulation technology available to undergraduates as a way to give students more “hands-on experience” in an era when university machine shops and foundries were being eliminated. Simulation (and the use of computers in general) is discussed here and in other sections as a generally positive development for students with disabilities, because of the computer’s great potential as an accommodation. However, as in other areas of education, if simulation, design, or other scientific software is not created with accessibility in mind, or if it cannot be made accessible via other software, then it is no less an obstacle than was the machine shop of the previous era. Surveys of computer usage could lead to a better understanding of accessibility problems, and that could in turn suggest avenues for making these technologies more accessible.

Team and Group Work

Another distinguishing feature of engineering education

and, to some extent, science, is its current reliance on team and group work and teambuilding approaches to class projects. These may be lab-based or not, but the dynamics of team participation and students with disabilities is still largely unexplored. So far as it goes, the literature that exists on this subject, which is based on middle- and high-school experiences but assumed to be applicable to lower level undergraduate courses, treats this as a form of accommodation, by reassigning duties in the team based on ability, or by bringing in an assistant to do the manual part of teamwork for a student with a physical limitation. The problem of working in teams is much broader, however, in higher level courses, where students take a multitude of roles, often do their work outside the formal classroom or lab, or where groups re-form themselves more than once during a semester. Further, there is the question of whether an accommodation replaces too much of the intended educational experience, analogous to the way it presumably degrades the “authentic” experience of fieldwork in science. Unfortunately, UDL approaches to teamwork at the college level have not yet been proposed.

A separate but related phenomenon is the longstanding relationship between engineering educators and the corporate workplace. Employers, who have always played a major role

in shaping the engineering curriculum, have long been relied upon to provide specific, "field" experience to engineering undergraduates. This experience is sometimes gained after graduation, placing it outside the scope of this study, but it is often preceded by summer internships and/or cooperative education/employment programs that are directly or indirectly sponsored by educational institutions. Students and parents are known to seek out certain engineering programs based on the quality of their "co-op" programs. Thus the importance of these informal learning environments should not be underestimated. Yet the success of students with disabilities in such situations is not known, and this is a major shortcoming of the state of research (Melber & Brown, 2008).

APPENDIX

**PROJECTS FUNDED BY THE NATIONAL SCIENCE
FOUNDATION RESEARCH IN DISABILITIES
EDUCATION PROGRAM
2005-2011**

Title	Start Date	Expiration Date	
Exploring Enabling Technologies, Best Practice Science Pedagogy, and Bilingual/ESL Strategies for the Teaching of Science to Elementary Deaf and Hearing Bilingual Students	15-Sep-05	31-Aug-06	
Tactile Mapping Software for Blind and Visually Impaired Navigation and Science Education	15-Sep-05	30-Jun-10	
Collaborative Research: Science of Learning Center: Visual Language and Visual Learning (VL2)	15-Sep-06	31-Aug-11	
Enhancing Access and Fostering Technology Based Education for Students with Disabilities	1-Jun-06	31-May-09	
Speech to Text Systems: Comparative Analysis of Text Generation and Display Methods	1-Sep-06	31-Aug-10	

	Principal	Organization	Abstract
	Andrews, Jean	Lamar University Beaumont	Enhanced learning for students who are deaf and those who have English as a second language.
	Lobben, Amy	University of Oregon Eugene	Provided/developed a model of environmental and thematic feature perception by blind and visually impaired map users.
	Allen, Thomas	Gallaudet University	Supported a research center bringing together deaf and hearing researchers and educators from a variety of settings.
	Lam, Paul	University of Akron	Increased the quantity and quality of students with disabilities in the Science, Technology, Engineering and Mathematics (STEM) education.
	Lalley, Peter	Rochester Institute of Tech	Tested the hypothesis that Automatic Speech Recognition (ASR) systems can be effective and cost-efficient alternatives to human-generated text generation systems or sign language interpreters, and that the method of displaying the information plays a crucial role in the learning process.

Title	Start Date	Expiration Date	
User Centered Digital Library: Transforming Resources for Individual Preferences	1-Sep-06	31-Aug-10	
Preparing Students with Learning Disabilities for Careers in Math and Science by Achieving Curriculum Standards	15-Aug-06	31-Jul-10	
SciTrain: Science, Math and Technology for All	1-Oct-06	30-Sep-11	
Software for Math Education for the Deaf	1-Dec-06	30-Nov-11	

	Principal	Organization	Abstract
	Rothberg, Madeleine	WGBH Educational Foundation	Created the capacity to transform and customize presentation of content based on individual user profiles within WGBH's TEACHERS' DOMAIN, a K-12 library of rich-media science resources that support standards-based teaching and learning.
	Meyen, Edward	University of Kansas Center for Research Inc	Reduced the achievement gap between the performance of students with learning disabilities and their non-disabled peers in math; enhanced the math preparation of individuals with LD to enter postsecondary institutions to pursue programs and degrees in math, science, engineering, and technology; and nationally disseminated instructional resources in the form of lessons and online tutorials aligned with curriculum standards .
	Todd, Robert	Georgia Tech Research Corporation	Enhanced the capacities of science, technology, engineering and mathematics (STEM) teachers in high schools.
	Wilbur, Ronnie	Purdue University	Reduced the achievement gap between the performance of students with learning disabilities and their non-disabled peers in math; enhanced the math preparation of individuals with LD to enter postsecondary institutions to pursue programs and degrees in math, science, engineering, and technology; and nationally disseminated instructional resources in the form of lessons and online tutorials aligned with curriculum standards.

Title	Start Date	Expiration Date	
Reaching the Pinnacle	1-Oct-06	31-Dec-12	
Sciences and Mathematics Integrated in Lifelong-Learning Experiences (SMILE); Fall 2006 and Spring 2007; Charleston, SC	1-Aug-06	31-Jul-08	
RDE-FRI: Supporting Math Access for Middle and High School Blind Students Through Adaptive Math Tutoring Technology (STEM Access)	1-Sep-07	30-Sep-09	
RDE-FRI: The Effects of Dyslexia on Scientists' Analysis of Astrophysical Data	1-Sep-07	31-Jan-10	
RDE-DEI: Universal Design in College Algebra: Customizing Learning Resources for Two Year Students with Learning Disabilities	1-Sep-07	28-Feb-10	
RDE-FRI: The Effectiveness of Texas Instruments Navigator Technology on Algebra I Achievement and Attitudes of High School Students with Learning Disabilities or Who are "At Risk"	1-Sep-07	31-Aug-10	

	Principal	Organization	Abstract
	King, James	New Mexico State University	Established “best practices” and provided services to students with disabilities in STEM education.
	Runyon, Cassandra	College of Charleston	Instilled confidence in kindergarten-12, undergraduate and graduate students with disabilities to pursue science, technology, engineering and mathematics (STEM) careers.
	Beal, Carole	University of Southern California	Addressed the relatively poor math achievement of middle and high school students who are blind and who have the academic ability to participate in STEM fields.
	Schneps, Matthew	Smithsonian Institution Astrophysical Observatory	Investigated the hypothesis that scientists who have dyslexia, when compared to those scientists without dyslexia, evidence context-dependent advantages and disadvantages when using and processing computer imaging displays.
	Fadden, Steven	Landmark College	Increased the number of students with learning disabilities who succeed in STEM courses and careers by making universally designed teaching and learning resources available to college algebra instructors and their students at public community colleges and two-year private colleges.
	Harper, Maxine	University of Mississippi	Determined the effectiveness of using Texas Instruments Navigator (TIN) technology with students who have learning disabilities, or who are at risk for academic failure, in high school algebra coursework.

Title	Start Date	Expiration Date	
RDE-FRI: Innovations in STEM Education for Blind Undergraduates Using Digital Pen-Based Audio/Tactile Graphics	1-Sep-07	31-Aug-11	
RDE-FRI: Independent Laboratory Access for Blind and Low Vision High School Students in the Mainstream Science Classroom	1-Nov-07	31-Oct-10	
RDE-FRI: Innovations in STEM Education for Blind Undergraduates Using Digital Pen-Based Audio/Tactile Graphics	1-Sep-07	31-Aug-10	
RDE-FRI: Effects of Teaching with Tablet PCs with Asynchronous Student Access in Post-Secondary STEM Courses on Students with Learning Disabilities (TTASA-SWLD)	1-Sep-07	31-Aug-11	

	Principal	Organization	Abstract
	Miele, Joshua	Smith-Kettlewell Eye Research Foundation	Developed, evaluated, and disseminated a low-cost, portable, easy-to-use digital pen technology that enables blind undergraduate students and educational support personnel (ESP) to create, explore, and understand the diagrams and figures common to the STEM curriculum using touch and sound.
	Mallouk, Thomas	Pennsylvania State University Park	Incorporated low-cost tools and instructional techniques for blind and low vision (BLV) students, previously created by the RDE-funded Independent Laboratory Access for the Blind (ILAB) team (HRD-0435656), into mainstream high school science classrooms so that BLV students can independently conduct science laboratory experiments.
	Van Schaack, Andrew	Vanderbilt University	Developed, evaluated, and disseminated a low-cost, portable, easy-to-use digital pen technology that enables blind undergraduate students and educational support personnel (ESP) to create, explore, and understand the diagrams and figures common to the STEM curriculum using touch and sound.
	Graves, Laura	Tennessee Technological University	Investigated the academic success, academic persistence and attitude of students with learning disabilities in postsecondary STEM courses when instructors use tablet PCs and provide students with asynchronous access to all course lecture content.

Title	Start Date	Expiration Date	
RDE-FRI: Improving Access to STEM for Community College Students with Disabilities in Universally Designed Learning Communities	1-Sep-07	31-Aug-11	
RDE-FRI: Supporting Deaf and Hard of Hearing Undergraduate Students in STEM Field Settings with Remote Speech-to-Text Services	1-Sep-07	31-Aug-10	
RDE-DEI: Developing and Evaluating a Peer Led Team Learning Curriculum in Calculus and Chemistry for Undergraduate Students with Learning and Attention Disabilities	1-Sep-07	31-Aug-10	
RDE-FRI: The Effects of Simulation Enhanced Training for Teachers on the Science Achievement of Third and Fourth Grade	1-Sep-07	31-Aug-11	
RDE-DEI: Access By Design: A Faculty Development Model of STEM Education for Undergraduate Students with Disabilities	1-Oct-07	31-Mar-10	

	Principal	Organization	Abstract
	Tamarkin, Dawn	Springfield Technical Community College	Created and tested the effectiveness of a student learning community model for community college students with disabilities in science, technology, engineering and mathematics (STEM).
	Stinson, Michael	Rochester Institute of Tech	Addressed the unmet need for Deaf and Hard of Hearing (D/HH) students to have wireless access to real-time speech-to-text services (RT-STTS) in varied outdoor and indoor settings.
	Koff, Robert	Washington University	Improved the academic outcomes for undergraduate students with learning and attention disabilities in gateway calculus and chemistry courses by implementing the use of an adapted peer led team learning (APLTL) program.
	Tyler-Wood, Tandra	University of North Texas	Trained elementary school teachers in effective teaching strategies so that third and fourth grade students with disabilities will experience effective science education and improve their science achievement.
	Ayala, Emiliano	Sonoma State University	Improved the success of undergraduate students with disabilities taking STEM courses by providing faculty the skills, support and training necessary to ensure student learning and academic success.

Title	Start Date	Expiration Date	
Collaborative Research: Universal Design of Inquiry-Based Middle and High School Science Curricula	15-Sep-07	31-Aug-11	
GSE/COM Girls Communicating Career Connections (GC3)	1-Jan-08	28-Feb-10	
Summit to Create a Cyber-Community to Advance Deaf and Hard-of-Hearing Individuals in STEM (DHH Cyber-Community)	1-Sep-07	31-Aug-09	
Increasing the Participation of Minority-serving Institutions in the Research in Disabilities Education Program	15-Sep-08	28-Feb-10	

	Principal	Organization	Abstract
	Rose, David	CAST, Inc.	Created heuristics for universally designed science materials for middle and high school instructional materials; built an open source UDL Inquiry Science System (ISS) that enables science curricula to be transformed into digitally supported versions that incorporate UDL features; and used the ISS to produce four UDL exemplars of chemistry and biology units from tested instructional materials and to evaluate the benefits of these exemplars for middle and high school students with and without learning disabilities.
	Nair-Pillai, Sarita	Education Development Center	Created a youth-produced, web-based media series and companion educator materials on science and engineering careers, targeting girls from underserved groups (minority populations, youth of low SES and those with disabilities).
	Clymer, Edward	Rochester Institute of Tech	Conducted a three day summit conference of 50 leaders in the field of support service provision for postsecondary deaf students in science, technology, engineering and mathematics (STEM) programs.
	McBay, Shirley	Quality Education For Minorities Network	Provided technical assistance to enhance disability support services at minority-serving institutions (MSIs) with STEM programs and to increase the participation of MSIs in the NSF's Research in Disabilities Education (RDE) program.

Title	Start Date	Expiration Date	
RDE-DEI: ACCESS TO ADVANCEMENT: An Audio Exploration of the National Effort to Increase the Role of Women with Disabilities in Science, Technology, Engineering and Mathematics	1-Jan-09	31-Dec-10	
MIND Alliance for Minority Students with Disabilities in Science, Technology, Engineering and Mathematics	1-Nov-08	31-Oct-12	
AccessSTEM: The Northwest Alliance for Students with Disabilities in Science, Technology, Engineering, and Mathematics-Phase II (AccessSTEM2)	1-Nov-08	31-Oct-11	
RDE-RAD: Collaborative Research: Increasing Achievement and Transition outcome in STEM Professions of Post-Secondary Students with Disabilities	1-Dec-08	30-Nov-12	
RDE-RAD: EAST Alliance for Students with Disabilities in STEM- Phase 2	1-Oct-08	30-Sep-12	
Disseminating Effective Practices for Describing STEM Content for People who are Blind or Visually Impaired	1-Oct-08	30-Sep-10	

	Principal	Organization	Abstract
	Busby, Glenn	WAMC Northeast Public Radio	Produced nationally-distributed radio programs aimed at playing an important information dissemination role in the national effort to broaden the participation and achievement of women with disabilities in all fields of STEM education and associated professional careers.
	Cardoso, Elizabeth	CUNY Hunter College	Aimed at retaining, graduating and transitioning students with disabilities for entry into community college and baccalaureate STEM degree programs, graduate programs, and the workforce.
	Burgstahler, Sheryl	University of Washington	Increased the associate, baccalaureate, and graduate science, technology, engineering and mathematics (STEM) degree attainment of individuals with disabilities in the Seattle, WA region.
	Izzo, Margaretha	Ohio State University Research Foundation	Increased the quantity and quality of students with disabilities receiving associate, baccalaureate and graduate degrees in STEM disciplines and their entry into the STEM workforce.
	Langley-Turnbaugh, Samantha	University of Southern Maine	Created a comprehensive “Pipeline of supports,” which will serve as a model for institutes of higher education nationally that are advancing high school, undergraduate, and graduate students with disabilities in STEM.
	Rothberg, Madeleine	WGBH Educational Foundation	Disseminated and institutionalized research-based practices for effective descriptions, for blind and visually impaired students, of non-text science, technology, engineering, and mathematics (STEM) content within electronic text.

Title	Start Date	Expiration Date	
RDE-RAD: Collaborative Research: Ohio's STEM Ability Alliance (OSAA): STEM Degrees and Careers for Ohioans with Disabilities	1-Dec-08	30-Nov-12	
The Signing Math Dictionary for Kids Project	15-Sep-08	31-Aug-11	
RDE-FRI Collaborative Research: Students with Learning Disabilities: STEM Pathways in the Social Context	1-Jan-09	31-Dec-11	
RDE-FRI Collaborative Research: Students with Learning Disabilities: STEM Pathways in the Social Context	1-Jan-09	31-Oct-09	
A Randomized Study of the Impact of STEM Mentors with Disabilities on High School Students with Disabilities	1-Oct-08	30-Sep-11	

	Principal	Organization	Abstract
	Flach, John	Wright State University	Increased the quantity and quality of students with disabilities receiving associate, baccalaureate and graduate degrees in STEM disciplines and their entry into the STEM workforce.
	Vesel, Judy	TERC Inc	Used the SigningAvatar accessibility software to: develop a 3D dictionary of mathematics terms and definitions, research how it furthers understanding of standards-based mathematics content, command of the language of mathematics, and the ability to study mathematics independently, and created a more robust sign/facial expression/body-space lexicon of signed mathematics terms that other developers can use when generating signed mathematics materials.
	Muller, Chandra	University of Texas at Austin	Explored the effects of high school context, social and academic processes, as well as variations by demographic subgroup among the population of students with learning disabilities, on college preparatory STEM achievement outcomes.
	Callahan, Rebecca	University of Georgia Research Foundation Inc	Explored the effects of high school context, social and academic processes, as well as variations by demographic subgroup among the population of students with learning disabilities, on college preparatory STEM achievement outcomes.
	Powers, Laurie	Portland State University	Investigated the impact of mentoring by adults with disabilities on youth with disabilities in STEM.

Title	Start Date	Expiration Date	
EPSCOR: Plains Indian Sign Language: Fieldwork and Digital Archive Project	1-Sep-09	31-Aug-11	
Enrichment : Testing the Concept of a Virtual Alliance for Deaf and Hard of Hearing STEM Students at the Postsecondary Level	1-Sep-09	29-Feb-12	
Tactile Mapping Dissemination Project	15-Sep-09	31-Aug-11	
Spectrum Support Program (SSP): A transition and support program for students with Autism Spectrum Disorders pursuing degrees and careers in STEM fields	15-Sep-09	31-Aug-11	
The At Ease Project	1-Oct-09	30-Sep-11	

	Principal	Organization	Abstract
	Davis, Jeffrey	University of Tennessee Knoxville	Documented and provided linguistic descriptions of contemporary Plains Sign Language varieties, and for sign language linguists to collaborate with deaf and hearing members of American Indian signing communities.
	Clymer, Edward	Rochester Institute of Tech	Advanced the knowledge of how students who are Deaf and hard of hearing access a cyber-enabled social and support network in STEM education.
	Lobben, Amy	University of Oregon Eugene	Disseminated products about tactile mapping for students who are blind or visually impaired learning STEM.
	Boulais, Nicole	Rochester Institute of Tech	Demonstrated success for undergraduate students with Autism Spectrum Disorders (ASD) entering, succeeding and completing Science, Technology, Engineering, and Mathematics (STEM) degree programs at Rochester Institute of Technology (RIT) and transitioning to the STEM workforce.
	Kozuch, Kris	Springfield Technical Community College	Recruited, retained, and supported returning combat veterans with disabilities in selected Engineering Technologies Certificate of Completion (COC) programs in STEM fields, with the aim of creating a reproducible model.

Title	Start Date	Expiration Date	
Universal Design and Technology for Students with Disabilities in STEM Fields	1-Sep-09	31-Aug-11	
RDE Collaborative Dissemination Project	1-Oct-09	30-Sep-11	
Pacific Alliance for Supporting Individuals with Disabilities in STEM Fields Partnership (Pacific Alliance)	1-Oct-09	30-Sep-11	
Building an Alliance for New Careers in STEM (KC-BANCS): A Collaborative Model for the Inclusion of Youth and Veterans with Disabilities	1-Oct-09	30-Sep-12	

	Principal	Organization	Abstract
	Kaylor, Maria	University of Texas at San Antonio	Studied how Hispanic students with disabilities transition from high school to post-secondary education, which student interventions and faculty training strategies improve the success of Hispanic undergraduate students completing Algebra and Pre-Calculus gateway courses, and how Hispanic-serving institutions collaborate with regional minority-serving secondary and post-secondary institutions to collect baseline data and pilot student interventions for a future Alliance for Students with Disabilities in STEM.
	Burgstahler, Sheryl	University of Washington	Increased awareness of how people with disabilities can be successful in STEM, strategies and resources for making STEM welcoming and accessible to people with disabilities, and increased collaboration of RDE-funded projects with respect to dissemination.
	Stodden, Robert	University of Hawaii	Increased the numbers of individuals with disabilities in STEM postsecondary education programs and ultimately the STEM workforce in Hawaii.
	Jenson, Ronda	University of Missouri-Kansas City	Increased the participation and success of high school and college students with disabilities within the Kansas City region in STEM education pathways.

Title	Start Date	Expiration Date	
Collaborative Research: Alabama Alliance for Students with Disabilities in STEM	1-Oct-09	30-Sep-12	
STEM STARS	1-Jan-10	31-Dec-11	
Collaborative Research: Improving STEM Learning through Interactive RoboBooks	1-Sep-09	31-Aug-11	
Spatial Thinking in the Curriculum of Students who are Blind or Low Vision	15-Sep-09	31-Aug-11	
Investigating Strengths People with Learning Differences Bring to STEM	1-Sep-09	31-Aug-10	

	Principal	Organization	Abstract
	Qazi, Mohammed, Jenda, Overtoun and Pettis, Carl	Tuskegee University, Auburn, University, Alabama State University	Increased the quality and/ or number of students with disabilities completing associate and baccalaureate degrees in STEM disciplines, entering and completing STEM graduate degrees or entering the STEM workforce, and generally increased the number of high school students with disabilities going to college.
	Shaw, Mary	New Mexico Highlands University	Studied how Hispanic and Native American undergraduate students with disabilities successfully complete gateway Algebra, Pre-Calculus and Biology course given access to a unique group of student interventions and faculty training.
	Murray, Elizabeth and Rogers, Chris	CAST, Inc., Tufts University	Developed RoboBooks, a novel interactive cyberenabled workspace for high school students with learning disabilities and/or behavioral/ emotional disabilities that will improve their science understanding in chemistry and physics.
	Lobben, Amy	University of Oregon Eugene	Advanced the knowledge of how students who are blind or visually impaired learn spatial thinking, a cornerstone of science and mathematical learning.
	Schneps, Matthew	Smithsonian Institution Astrophysical Observatory	Advanced knowledge about the neurological differences associated with undergraduate students with dyslexia that can lead to advantages for visual processing and learning in STEM.

Title	Start Date	Expiration Date	
Preparing for College: Using Technology to Support Achievement for Students with Learning Disabilities in Mathematics	1-Oct-09	30-Sep-11	
OEDG Planning Grant: Expanding Geoscience Diversity: Alternative Field Environments for Non-Traditional Students	1-Oct-09	30-Sep-11	
RDE-FRI: Supporting Math Access for Middle and High School Blind Students Through Adaptive Math Tutoring Technology (STEM Access)	1-Apr-09	31-Jul-10	
Making Simulated Biology Laboratories Accessible to Visually-Impaired Students	1-Apr-10	31-Mar-12	
Building an Integrated Identification, Engagement and Assessment Infrastructure for STEM Enrichment Programs at Hunter College	1-Jun-10	31-May-12	

	Principal	Organization	Abstract
	Woolf, Beverly	University of Massachusetts Amherst	Advanced knowledge about improved learning, motivation and achievement of undergraduate students with mathematics learning disabilities when using digital interventions.
	Stredney, Donald	Ohio State University Research Foundation	Explored new strategies for engaging persons with physical limitations in geologic field work through surrogate, immersive, virtual representations, with the goal of bringing more diverse students into the geosciences
	Beal, Carole	University of Arizona	Addressed the relatively poor math achievement of middle and high school students who are blind and who have the academic ability to participate in STEM fields.
	Steinberg, Eleanor	SimBiotic Software	Incorporated audio and tactile tools for making simulated experiments in virtual biology laboratories accessible to blind and low vision students are being explored.
	Rabinowitz, Vita	CUNY Hunter College	Transformed how STEM enrichment programs are made available to students at CUNY Hunter College, facilitating faculty work in the area of student education within STEM enrichment programs and collaboration across programs, and leveraging the intellectual capital of current grant-funded programs.

Title	Start Date	Expiration Date	
RDE-FRI Collaborative Research: Students with Learning Disabilities: STEM Pathways in the Social Context	15-Aug-09	31-Mar-12	
Response to Intervention in Mathematics: Beginning Substantive Collaboration between Mathematics Education and Special Education	1-Sep-10	29-Feb-12	
Signing High School Science	1-Sep-10	31-Aug-13	
Creating a Web Presence for the I3 Track	1-Oct-10	30-Sep-12	
Collaborative Research: Georgia STEM Accessibility Alliance (GSAA)	1-Oct-10	30-Sep-12	

	Principal	Organization	Abstract
	Callahan, Rebecca	University of Texas at Austin	Explored the effects of high school context, social and academic processes, as well as variations by demographic subgroup (racial, ethnic and linguistic minority, gender, class) among the population of students with learning disabilities, on college preparatory STEM achievement outcomes.
	Yang, Kichoon	National Council of Teachers of Mathematics	Held a conference on Response to Intervention (RtI) and related strategies in teaching and assessment in Mathematics.
	Vesel, Judy	TERC Inc	Integrated American Sign Language (ASL) into the life and physical sciences content of 9th-12th grade deaf or hard of hearing students.
	Falk, Joni	TERC Inc	Created an Internet Web presence for the Innovation through Institutional Integration (I-3) community and for the broader STEM community that is interested in NSF's integrative, innovative and institutional endeavor that is I-3.
	Gregg, Noel and Todd, Robert	University of Georgia Research Foundation Inc, Georgia Tech Research Corporation	Established an alliance between Georgia Institute of Technology, the University of Georgia, Georgia Perimeter College and three public secondary school districts. All project activities support the goal of increasing the postsecondary STEM degree and career attainment of individuals with disabilities.

Title	Start Date	Expiration Date	
Analyzing the Use of C-Print Mobile Technology in STEM Lab Settings across Multiple Postsecondary Sites	1-Sep-10	31-Aug-13	
A Cluster Randomized Study of Heuristic Teaching vs. Intelligent Tutoring for Community College Students with Disabilities in Algebra	1-Oct-10	30-Sep-13	
STEM Collaboration Workshop for TCUP, RDE and REESE Communities	1-Oct-10	30-Sep-13	

	Principal	Organization	Abstract
	Stinson, Michael	Rochester Institute of Tech	Expanded the types of venues in which the service (C-Print Mobile software) is used to several other universities, a community college, and institutions with RDE-funded Alliances for Students with Disabilities in STEM; and conducted experimental investigations to evaluate the extent to which the service aids students' access and learning in STEM labs at the postsecondary level.
	Stodden, Robert	University of Hawaii	Investigated of the effectiveness of two intervention strategies for problem solving on the performance of community college students with disabilities in an Elementary Algebra I course and persistence in STEM coursework and degree programs.
	Powless, Donna	College of the Menominee Nation	Brought together educators and leaders of RDE, REESE and TCUP awards for pre-workshop virtual communication, three subsequent workshops, and post-workshop virtual networking.

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