APPROVAL SHEET

Title of Dissertation: Exploring Inclusive Learning Interactions for Students with Intellectual Disabilities in Postsecondary Education

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ABSTRACT

Title of Document: EXPLORING INCLUSIVE LEARNING INTERACTIONS FOR STUDENTS WITH INTELLECTUAL DISABILITIES IN POSTSECONDARY EDUCATION.

Erin Buehler, Ph.D., 2018

Directed By: Dr. Amy Hurst
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Advances in mechanical and electrical engineering and an evolving workforce have prompted education systems in the United States to incorporate technology as both a subject of learning and a pedagogical tool. The rising workforce must be literate in the use, maintenance, and creation of technologies as more labor and service jobs become automated. People without access to this education find themselves at a severe disadvantage. The issue is further compounded for individuals with intellectual disabilities who are underemployed and who are unlikely to pursue or receive education beyond the secondary level. I assert this shift to digital literacy introduces new barriers to learning and employment stemming from the accessibility of new technologies themselves.

My dissertation presents three-and-a-half years of research exploring the issue of accessible and inclusive technology education through the lens of 3D printing. I have studied the practices of teaching 3D printing in both mainstream and special education, formal and informal environments,

and at many age and education levels. I have explored the applications of 3D printing in these same spaces and identified discrepancies in access to this technology.

My contributions from this body of work include (1) a deep understanding the role of technology in education for persons with disabilities, both as a subject and a medium of learning, and (2) recommendations and best practices for 3D printing with an emphasis on improving access to 3D printing and how this technology can benefit persons with disabilities.

By unpacking the learning experiences surrounding 3D printing, I hope to draw attention to the larger problem of accessible technology education for students with disabilities. Three-dimensional printing is one example of an ever-growing trend in developing technologies that each subsequent generation of students must master in order to have a chance at seeking and gaining employment. I believe technologists must work in concert with educators and students of all abilities to ensure the accessibility of both the content and the pedagogical instruments being used to bring these students into a new age of digital education and employment.

EXPLORING INCLUSIVE LEARNING INTERACTIONS FOR STUDENTS WITH INTELLECTUAL DISABILITIES IN POSTSECONDARY EDUCATION

By

Erin Buehler

Dissertation submitted to the Faculty of the Graduate School of the
University of Maryland, Baltimore County, in partial fulfillment
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Dedication

[ded-i-**key**-sh*uh* n]
noun
A formal, printed inscription in a book, piece of music, etc., dedicating it to a person, cause, or the like.

– Wait, what do you mean that's not what I'm supposed to put on this page?

Acknowledgements

Have you ever considered the anagrams of the word "*dissertation*"? I have many people to thank in this jumble of letters that make up a doctoral thesis and I'm confident anagrams are the key.

Diarist notes. An academic advisor must wear many hats and fill many roles, little did mine know she would have to be on the receiving end of my dear diary woes for so many years.

Saint editors. The kind folks on my committee not only read this document and gave me feedback throughout countless drafts and revisions, but also tolerated my group emails.

Sedation stir. However much of my humanity came out the other side of this degree, I owe it to the masterful mixing of liquid courage and encouragement from my Swamp family.

Tarots inside. All of the stakeholders who have offered me their insights, entrusted me with their stories, and gave me their time. This work does not exist without each of you.

Stars edition. My wife is far brighter than Polaris, but she has absolutely been my guiding star during this arduous journey.

Roadie stints. All the family and friends who still know and remember me fondly after this last long tour. Well, sorry for the inconvenience—I promise I'll never do it again.

Arsonist diet. For everyone I've forgotten to thank, my memory is smoke on the breeze these days.

For you, reader, I'm grateful for your attention. If you happen to be considering the path to a doctorate, let me leave you with this one piece of advice: *Instead, riots.*

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List of Abbreviations

3D – Three-Dimensional

AAC – Alternative and Augmented Communication

AAIDD – American Association for Intellectual and Developmental Disabilities

ABC – Antecedent Behavior Consequent

AT – Assistive Technology

CAD – Computer-Aided Drafting

CNC – Computer Numerical Controlled

DIY – Do-It-Yourself

EF – Executive Function

EHA – Education for All Handicapped Children Act

ENTR – Entrepreneurship

FDM – Fused Deposition Modeling

FFF – Fused Filament Fabrication

GED – General Education Diploma

ICT – Information and Communication Technology

ID/IDD – Intellectual (and Developmental) Disability

IDEA – Individuals with Disabilities Education Act

IEP – Individual Education Plan

ILE – Inclusive Learning Environment

HCI – Human-Computer Interaction

OT – Occupational Therapist

PSE – Postsecondary Education

PT – Physical Therapist

PWD – Person(s) with Disability

STEM/STEAM – Science Technology Engineering (Art) Mathematics

UDL – Universal Design for Learning

UG – Undergraduate

1 Introduction

1.1 Background on Intellectual Disability, Education, and Employment

Intellectual disability (ID) affects over 3,000,000 people in the United States. The American Association on Intellectual and Developmental Disabilities (AAIDD, 2012) defines ID as, "…a disability characterized by significant limitations in both intellectual functioning and in adaptive behavior… . This disability originates before the age of 18." Intellectual function is related to an individual's ability to learn or reason, and adaptive behaviors are a set of skills necessary in everyday life. These skills include conceptual (literacy, time, money), social (interpersonal relations, self-esteem), and practical (activities of daily living, safety).

Intellectual disability is also a highly heterogeneous diagnosis, as it is an umbrella term for developmental disability based on observable behaviors rather than a specific medical condition. As such, persons with ID may be diagnosed with Down Syndrome, Fragile X, Fetal Alcohol Syndrome, and so on, causing them to meet the diagnostic criteria for ID. With such a heterogeneous diagnosis comes a wide range of abilities and support needs for each individual. For example, one student with ID may need occasional additional support from a teacher or supervisor in the form of a verbal reminder once a week. Another student with a diagnosis of ID may need pervasive support to complete a task, such as an aide or a supervisor who prompts the student at each step to continue to the next in a procedural series.

Currently, over 60% of adults with ID are unemployed, and among those who are employed, only 50% receive wages comparable to that of their peers without disabilities (Siperstein, Parker, & Drascher, 2013). This combination of unemployment and underemployment can be tied to many factors including access to education, social misperceptions surrounding ability, and issues of individually perceived self-efficacy or self-esteem. People with intellectual disabilities who are employed are often in occupations completing vocational tasks or procedural retail jobs. While some people may find satisfaction in this type of work, there are more options for these individuals and they should be able to exercise self-determination in their selection of occupations. If self-determination were not argument enough, many vocational jobs that require assembly-line tasks are being phased out with more and more manufacturers turning to robotic automation and non-domestic assembly options (Berlin, 2017). There is also increasing demand for technically skilled labor. Entry-level and hourly-wage jobs now frequently require potential hires to have prior experience or exposure to multiple kinds of information and communication technologies (ICTs) (Purcell, 2014). Examples include using point-of-service devices for retail workers, stockers maintaining digital inventory with mobile devices, and the pervasive use of both mobile and desktop computing in office jobs. Without access to education and practical training in these technologies, adults with ID are at a further disadvantage in the job market.

The shape of education and employment in America has changed, and employers now seek candidates with associates or bachelor’s degrees where they once would have accepted a high school diploma or general education diploma (GED). For most persons with ID, education ends in high school and very few continue on to a postsecondary institute. Opportunities for education do exist, as there are over 240 postsecondary educational programs targeted toward adults with ID in the U.S. and Canada. Some are vocational or two-year colleges, and others are immersive four-year university experiences. However, support services are reduced for students transitioning from secondary to postsecondary education in the U.S.

In secondary education, schools are required to provide a high level of individualized instruction (U.S. Department of Education, 2011). This includes the creation of special education curriculum and other services designed to address the individual learning needs of students. Once a student transitions to the postsecondary level, support is reduced from customization to access. Special accommodations in this context include providing accessible course materials (accessible digital documents, Braille, or large-print), assistance accessing public or private tutoring, and help finding and applying for financial aid. For persons with learning disabilities or cognitive impairments, schools are required to offer extended test-taking time, but they do not have to provide individualized or otherwise special curriculum for these students.

Inclusive learning environments (ILEs), where students with disabilities take courses alongside their peers without disabilities, is a technique that has been growing in popularity in the special education field for several years (King-Sears, 1997). More specifically, King-Sears uses a variation of York's definition of inclusive learning that must include (1) students with disabilities attending school with other students in their community, (2) being in mainstream educational classrooms with age-appropriate peers,

(3) having individualized learning objectives, and (4) having necessary support (King-Sears, 1997; York, Doyle, & Kronberg, 1992). (This does not mean these students would never be in separate educational spaces nor that they would not receive specialized opportunities as dictated by their abilities and support needs.)

The integrated classroom can create a more individualized learning environment for students with disabilities while simultaneously exposing students without disabilities to this population and reducing associated social stigmas. Supporting students with highly heterogeneous levels of ability can be very challenging and is among the main concerns for detractors of inclusive education (Antony, 2012). The concept of an ILE is not to simply throw students with disabilities into the deep end without support, nor is it to reduce the quality or intensity of mainstream education for all students. King-Sears offers best practices for implementing inclusive learning that must be upheld at a systemic level in order to succeed. These practices include adjustments to curriculum delivery but not content (e.g., cooperative learning, strategy instruction, explicit instruction, collaboration), more individualized learning practices (e.g., differentiated instruction, generalization techniques, peer support and friendships), and avenues of assessments (e.g., self-determination, curriculum-based assessment, proactive behavior management) (King-Sears, 1997). Keeping all students engaged, ensuring learning outcomes, and reinforcing positive social interactions are important goals in this dynamic environment.

This mix of circumstances—underemployment, rising demand for technical skills, and limited access to postsecondary educational resources—creates a veritable obstacle course between a young adult with ID and meaningful employment. Societal misperceptions may also contribute to this problem, forcing workers with ID into menial jobs lacking both personal gratification and openings for advancement. It is essential that individuals with ID receive access to the skills they need to make self-determined decisions about their own employment and that the community at large be educated about the diversity and abilities of these individuals.

1.2 Statement of Purpose and Research Questions

Statement of Purpose

The purpose of this qualitative work is to explore and understand technology education and accessibility for students with intellectual disabilities through the lens of three-dimensional (3D) printing. The current academic literature contains very few descriptive explorations of technology accessibility and its relationship to education and employment for persons with ID. The motivation for my research is to draw attention to the need for accessible and inclusive technology education for students with disabilities and to identify how technology itself may hinder or help these individuals on their path to employment.

Central Research Questions

- What are the barriers to 3D printing education for individuals with intellectual and developmental disabilities?

Secondary Research Questions

- How is 3D printing being taught in mainstream education?
- What are the barriers to 3D printing in special education and for persons with disabilities?

- How might an inclusive learning environment mitigate barriers to 3D printing education?
- What is the role of technology in inclusive education?

Tertiary Questions

- What is the role of an educator in an inclusive learning environment?
- What tools, digital or analog, do educators use in ILE?
- What existent technologies, if any, might be applied in support of ILE?
- What hypothetical or next-step technologies should be explored to support educators in ILE?

To answer these questions, I have leveraged several qualitative research methods. These methods include field observations, interviews, ethnographic action research, and artifact and video analysis. Where and why these methods were used is explained in more detail in later chapters.

1.3 Significance and Contributions

This dissertation contributes to human-computer interaction, inclusive education, and the perpetually evolving discipline of 3D printing. My work has three primary branches of contribution with many smaller leaves and buds of contribution extending from each one.

1.3.1 Rich Description of Inclusive Postsecondary 3D Printing Course Environment and Stakeholders

I have provided rich descriptions of special and inclusive education learning environments and the challenges faced by young adults with intellectual disabilities while using classroom technologies. I have used my collection of data and the collaborative vetting of special education experts to build a framework for video interaction analysis for a special population (students with ID) and I have offered a robust set of implications for future designs in the space of technology-enhanced (or “smart”) inclusive learning environments.

1.3.2 Formative Research on 3D Printing, Special Education, and Special Populations

My research is among the formative work on 3D printing for special populations and special education. I have provided insights on the benefits of teaching 3D printing to students with disabilities, how the accessibility of this technology impacts students with multiple types of disability, such as motor, cognitive, and visual impairments. I have also generated many lessons learned for educators hoping to implement this technology and curriculum in their classrooms, including suggestions for how to maintain engagement, promote self-efficacy, and deal with the shortcomings of 3D printing as an emergent, consumer-grade technology.

1.3.3 Design Barriers for Novices Seeking to Leverage 3D Printing

By studying 3D printing in special education and with special populations, I have also generated explicit design barriers for novices seeking to leverage 3D printing in general and for the creation of bespoke assistive technologies (AT) and devices. This then led me to study how the barriers to entry for 3D modeling tools impacts the ability of persons with disabilities, their caregivers, and clinicians to access those applications and their benefits. This included a large survey of existing 3D-printable assistive technology, a better understanding of how accessibility and disability are represented in Maker culture, and in the creation of a prototype 3D design tool targeted to clinicians without 3D modeling training.

1.4 Structure of the Dissertation

<u>Chapter 1: Introduction</u>

This introduction provides a brief summary on intellectual disability and the obstacles faced by those with ID in the space of education and employment. It also outlines a statement of purpose, research questions, and the contributions of this work.

<u>Chapter 2: Relevant literature.</u>

This chapter covers the intersecting domains of study, including: (1) Intellectual Disability, (2) Assistive Technology for ID, (3) 3D Printing as It Relates to Special Populations, (4) Augmented Classroom Technologies, and (5) Inclusive Learning Environments and Universal Design for Learning (UDL).

Chapter 3: Methods

This is formative work exploring a special population, persons with intellectual disability and/or developmental disabilities, with unique challenges for data collection. The methods chapter describes my use of qualitative methods, the ethnographic action research framework, why these methods are an appropriate choice for this subject, what they capture, and what they do not capture.

Chapters 4 – 8: Research studies.

These chapters include motivation, methods, and relevant findings from my published research studies. My early studies identified important and often seminal contributions in the space of 3D printing and special education. Each subsequent study then extended the selective findings in new directions, leading to my final contribution in inclusive technology education.

Chapter 4: Teaching and learning strategies for 3D printing from mainstream education.

My goal for this study was to learn what the best practices were in mainstream education for teaching and learning 3D printing. This chapter details interviews I conducted with adult, mainstream educators and experienced youth designers who had learned and taught 3D printing in an informal learning environment. From this work, I identified potential overlapping needs and challenges for students with and without disabilities. I also created a curriculum toward teaching an integrated, inclusive version of a 3D modeling and printing class that I used in my later study designs.

Chapter 5: Exploring and adapting 3D printing learning in special education contexts.

In order to identify the potential benefits and drawbacks of 3D printing in special education, I gathered observations during a year-long field study in a special education classroom and I conducted semi-structure interviews with faculty, staff, and technologists at multiple investigation sites. This chapters offers findings on the value of 3D printing in special education, the perceptions of the stakeholders involved, and provides descriptions of obstacles facing instructors in special education and students with disabilities learning 3D modeling and 3D printing.

Chapter 6: Understanding a use-case of 3D printing for special populations and the lacking representation of people with disabilities in Maker communities.

While I gathered data at the special education sites described in Chapter 4, I also identified a potential application for 3D printing as a means to generate custom assistive technology. This chapter discusses a survey of existing 3D-printed AT available on a large, open source repository and speaks to the benefits of bespoke, 3D-printed AT, the barriers to creating such devices for stakeholders (including persons with disabilities and Makers without disabilities), and the need for more attention, communication, and inclusion for persons with disabilities in technology and Maker culture.

Chapter 7: Applying inclusive learning techniques in a postsecondary educational environment for 3D printing.

Utilizing the findings from the interviews I conducted with stakeholders in mainstream 3D printing education and my studies in special education, I developed and taught a course on 3D modeling and printing at the postsecondary level. This course included students with and without intellectual disabilities. I taught and collected data on three iterations of this course, one semester each, over three years. The data I captured included field observations, student assignment deliverables, and video of students during lab activities (final two semesters). Each semester I iterated on the course design and further explored the obstacles to 3D modeling and printing. These findings touched on the accessibility of the design tools, the social dynamics between students with and without disabilities, and the barriers to technology education for young adults with ID.

Chapter 8: Identifying roles for technology in the inclusive learning environment.

My final study in this dissertation was an exploration of the role and impact of technology in a technology-driven class for students with disabilities. This included an open analysis of the observations and video data collected in the previous studies conducted with a focus on interactions rather than 3D modeling and 3D printing ability. These findings were then used to guide semi-structured interviews with expert special educators who evaluated video fragments from the class and identified the behaviors they deemed most relevant to positive or negative learning interactions. From those interviews, I created a video coding schema to help identify significant interactions between students and to determine what, if any, role technology can have in mediating or supporting inclusive learning.

Chapter 9: Discussion.

In my discussion, I unpack the observations and patterns identified in my studies and how these relate to prior literature and the high-level question of this dissertation. Using 3D printing as a case study, I describe the technology barriers for students with IDs, the patterns I observed in designing and teaching my own inclusive 3D printing course, my efforts to mitigate these accessibility barriers, and how technology plays a role in the future of education, both as a subject and a medium of learning.

Chapter 10: Conclusions, limitations, and future work.

The final chapter of this document discusses the limitations of these studies and reiterates the contributions and conclusions yielded by this research arc. The limitations include the mercurial nature of technology development, the challenges of working with special and protected populations, and the potential hazards of ethnographic research methods. The contributions and conclusions touch on a multitude of technology-based barriers for students with IDs and the potential solutions for these issues in the form of existing special education and behavior theory paired with technology, and a brief discussion of the contributions I have made to furthering 3D printing as a medium of learning and design for persons with disabilities.

Appendices, glossary, and references.

The remaining sections of this document include the works cited, a glossary of terms relevant to both 3D printing and special education, and, wherever possible, protocols and study instruments from this body of work.

2 Relevant Literature

Assistive technologies and augmented or “smart” classrooms are both well represented in human-computer interaction (HCI) literature, but there is very little in the way of technology for inclusive learning environments. The domain and contributions from my work overlap both technology design and special education literature. To assist my readers in situating this work, I have provided an extended description of my study population (2.1) and a review of the related literature in assistive technology for persons with ID (2.2), background information on 3D printing as it relates to special populations (2.3), augmented classrooms (2.4), and inclusive learning environments and practices (2.5).

2.1 Intellectual Disability Diagnosis and Support Needs

Intellectual Disability is a diagnosis under the broader category of developmental disabilities. Developmental disabilities can include cognitive or physical disabilities or both and are onset during childhood. As defined by the American Association of Intellectual and Developmental Disabilities (AAIDD), an intellectual disability is characterized by limitations to both intellectual functioning and adaptive behavior (AAIDD, 2012). As the ID diagnosis is characterized by individual ability rather than a specific medical condition, there is more than one potential cause for ID. One example of a condition associated with intellectual disability is Down Syndrome—a genetic disorder related to the number of one’s chromosomes. Cognitive impairments are characteristic of persons with ID, but are not exclusive to this population. A person who experiences a stroke or a decline in certain neurological functions later in life can have a cognitive impairment, but they would not be considered intellectually disabled. In the literature, studies may focus on a specific condition (e.g., Down Syndrome or Fragile X Syndrome), umbrella diagnosis (e.g., intellectual or developmental disability), or specific limitations (e.g., mild cognitive impairment). The majority of my work has been conducted with young adults with intellectual disabilities.

It is important to understand the limitations associated with ID. Issues of intellectual functioning and adaptive behavior include many everyday social and practical skills (e.g., planning one’s schedule, appropriate conduct in the workplace, changing currency for a purchase, etc.). Another characteristic associated with intellectual disabilities is how it affects Executive Functioning (EF) (AAIDD, 2012). Executive Functioning is a deficiency in the cognitive management systems of the brain that can affect processes such as planning, organization, strategizing, paying attention to and remembering details, and managing time and space. Students with ID can execute a series of actions, but sometimes need prompts to begin a task or require more guidance during an interaction. While it may be intuitive for a student without ID to navigate to and explore a website to find what they need, a student with ID may hesitate or freeze without a clear path to their task. Executive functioning also affects the ability for students with ID to plan out the steps to move forward. For example, when students are navigating a website, it is difficult to plan where to look for information on the website and what information to look for.

Developing support strategies for persons with ID is highly individualized. Each student has support needs relevant to their personal ability and the context of the task they are completing. This can take the form of technology-based solutions, such as alternative and augmented communication devices (AACs) to help with interpersonal communication or calendar applications to assist with scheduling and planning. But support can also come in the form of other people, such as a job coach or classroom aide. Even receiving a prompt from a community member, such as a public transit bus driver reminding the student of their desired bus stop, can be considered a source of support (Coulter, Buntinx, Craig, Borthwick-Duffy, & Schalock, 2012).

Intellectual disability occurs at a rate of approximately 1 in every 10,000 children globally, with boys being diagnosed with ID at a frequency of 5:1 over girls (Maulik, Mascarenhas, Mathers, Dua, & Saxena, 2011). Life expectancy for these individuals varies by personal health and medical diagnosis, but the overall average lifespan is 66 (Coppus, 2013). As adults, these individuals may live independently, reside in community living spaces with additional supports for daily living and/or employment, or remain with a legal guardian, often a parent or family member. Statistics on technology use for people with intellectual disabilities are limited, but what has been collected suggests that these individuals use and access contemporary technologies at a significantly lower rate than their peers (Bryen, Carey, Friedman, & Taylor, 2007). This may be due to multiple factors, including lack of financial resources, technology education, or interface accessibility. Persons with ID experience a high rate of unemployment (60%) and those who are employed are often paid significantly less than their peers without disabilities (Siperstein et al., 2013). Without access to education and resources that promote self-determination and independence, these individuals may remain unemployed and dependent on caregivers.

Many of my studies presented in this document are specific to individuals with ID and address issues of access to education and specifically technology education. Without technology education, these individuals are at a disadvantage in the job market. My work seeks to draw attention to the disparities in education support, the accessibility of everyday technologies, and the need for more inclusive practices both in the classroom and in the design of technologies. It is important to note that while ID is not a highly prevalent diagnosis, the social behaviors and intellectual impairments associated with it are also found in many other diagnoses. There is no one-size-fits-all for cognitive impairment, but technology considerations for this highly heterogeneous population may improve the user experience for a range of individuals with similar cognitive impairments such as traumatic brain injury, dementia, or Alzheimer's. This could include accessibility enhancements or novel technology applications assisting individuals with impairments to their learning, memory, perception, or problem-solving abilities.

2.2 Assistive Technology for Persons with Intellectual Disabilities

Literature surrounding Intellectual Disability and technology use exists, but as a heterogeneous diagnosis falling under an umbrella of developmental disability, it can be tricky to unearth relevant studies. Erring on the side of additional information, I am choosing to include a limited discussion of not just studies concerning people with ID, but also on single diagnosis (e.g., Down Syndrome) and broader descriptions of disability (e.g., cognitive impairment). These studies often touch on interface design, taking into consideration common traits of users with limited recall over recognition, difficulty with abstract or ambiguous language and iconography, and the effects of potential compounding diagnoses with physical repercussions on input device use.

Feng and Lazar have conducted several studies in the arena of technology use by persons with Down Syndrome, including their work with Hu *et al.*, where they evaluated the input interactions of children with Down Syndrome, including keyboard and mouse input, voice recognition, and word prediction techniques. They noted that individual performance and preference among users varies greatly (Hu, Feng, Lazar, & Kumin, 2013). Hu *et al.* presented findings related to information search (Hu & Feng, 2015). They conducted an empirical study with adults with cognitive impairments into search methods and navigation structure. Their findings suggest user preferences for search over navigation. Ma *et al.* have investigated authentication practices for persons with Down Syndrome and have identified issues surrounding typographical errors and spelling related to failed authentication, and issues of memory/recall when selecting passwords (Ma, Feng, Kumin, Lazar, & Sreeramareddy, 2012; Ma, Feng, Kumin, & Lazar, 2013).

Other studies focus more specifically on skills building and how technology might support education or employment for populations with different types of developmental and cognitive impairment. Funk *et al.* designed and tested an augmented reality system for use by people with ID. The system was designed to overlay visual instructions to be completed as part of a linear task completion process (Funk, Mayer, & Schmidt, 2015). Systems like this encourage the user to complete steps broken down into single components, but do not necessarily focus on teaching the user about the process they are completing nor how to do it independently. Examples of a more teaching and practice focused system was a specialized app built and tested by Kurniawan and co-authors. They designed an interactive learning program implemented on mobile devices for people with a range of developmental disabilities that offered activities to practice cognitive skills, such as recognizing shapes or making change with currency (Buschmann, Morales, & Kurniawan, 2014; Morales-Villaverde, Caro, Gotfrid, & Kurniawan, 2016). Activities like these build individual skill, but not focus on the social and behavioral deficits of learners.

A technology tool that deals with social behavioral practice is Incloodle, by Sobel *et al*. This is a system for cooperative play targeted at younger learners. This work was conducted in a lab setting, but focused on technology as a means to mediate cooperative play and encouraged children to take turns using various scaffoldings (Sobel, Rector, Evans, & Kientz, 2016). The focus of this work was exclusively on cooperative play and no additional studies in this vein have been published by the authors at the time of this writing. The authors were unable to determine the strict value of technology-reinforced inclusive play, but they felt their efforts at incorporating character prompts and interactive activities were valuable in support social and inclusive play. Along the lines of play, another example of non-neurotypical play spaces is Ringland's work on the appropriation of Minecraft as a safe and social space for children with autism (Ringland, Wolf, Boyd, Baldwin, & Hayes, 2016). This is a good example of how everyday technology can be leveraged for a special population, although in this instance the parents of the children involved are the actors repurposing the tool and building an assistive and inclusive environment for their children, rather than the children having the self-determination and necessary technology skills to construct such a space on their own.

While there are examples of assistive technologies for individuals with intellectual and developmental disabilities, most of those discussed have had an emphasis on training a skill rather than learning or have lacked the accessibility and usability needed for primary stakeholders (those with disabilities) to build or leverage these tools directly. My dissertation helps to underscore that many of these user experience and design considerations do not appear in the basic software and technology being used to teach in postsecondary education. The inclusive postsecondary study I describe in Chapter 7 confirms many of the challenges described by previous authors, and I build on these findings to discuss how peer intervention might mitigate these issues. I have also gathered descriptions from special educators about ways in which educational and behavioral practices might be incorporated into classroom technology design, reducing the need to rely solely on individual AT. All of this research has been scoped to a single technology medium—3D printing.

2.3 3D Printers and Uses for Special Populations

I chose 3D printing as a lens to study technology access for a few reasons. Its low cost of entry and oft-touted ease-of-use meant that I would be able to acquire the necessary software and hardware tools, as opposed to other more expensive technologies. I also wanted to be able to contrast students with and without disabilities while learning a new technology. Students with disabilities, and particularly intellectual disabilities, were already more likely to have had less practice and exposure to everyday technologies like cell phones and desktop computers. Even though 3D printing relies on the ability to use desktop design software, the concept of modeling in three-dimensions and the hardware of the printers would be relatively novel to both students with and without disabilities, creating as scenario where everyone is being forced to address and learn a new technology. There was an additional incentive to 3D printing because it could generate tangible outcomes and had promising applications for learning and entertainment.

Fused deposition modeling (FDM) is currently the most popular consumer 3D printing technique. FDM printer costs range from hundreds to thousands of dollars and these tools can create plastic models by layering small strands of heated material which hardens and bonds together solidifying into a 3D-object. The process of heating and depositing the plastic material is somewhat slow. The plastic material needs to be heated to a fluid state, but it must also be allowed enough time to solidify a small amount between layers to maintain the three-dimensional shape. One can increase the layer height and gain a small amount of speed, but this reduces the fidelity of the printed object (imagine decreasing pixel count to make the file size of an image smaller). To create these printed objects, users must either have access to an existing 3D model or use computer-aided drafting (CAD) tools to build such a model and then process this file for printing on their specific brand of printer (MakerBot[1], Ultimaker[2], Afinia[3], etc.).

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[1] http://www.makerbot.com/.

[2] https://www.ultimaker.com/.

[3] http://www.afinia.com/.

The physical affordances of 3D printed objects have made this technology a popular medium for tactile learning aids. Current research has explored applications of 3D printed graphics for students with visual impairments. Brown and Hurst (Brown & Hurst, 2012) presented VizTouch, an automated tool for generating 3D printable line graphs in the context of math education. Braier, *et al.* (Braier et al., 2014) wrote about the potential to provide inclusive education with 3D printed graphics and presented their own implementation of software to automate the creation of 3D printable tactile aids. Similarly, Kane and Bigham (Kane & Bigham, 2014) wrote about the use of 3D printed information as a tool for computer science education and science, technology, engineering, and mathematics (STEM) encouragement for youth with visual impairments. These works focus largely on generating 3D prints on behalf of populations with disabilities.

Do-It-Yourself (DIY) fabrication addresses two important issues in assistive technology—cost and customization. Financial costs of the device and assessment can be astronomical for the average user. Proper fit and personalization are key issues in AT abandonment. With 3D printing, end-users can create their own custom designs at reduced cost (Hurst & Tobias, 2011). Hurst and Kane (Hurst & Kane, 2013) offer example tools designed to make DIY more accessible to a variety of populations.

The studies in my dissertation contribute a significant amount of knowledge to 3D modeling and printing and the use of 3D printed objects for special populations. By using this novel technology as a lens, I was able to uncover both concerns for the immediate applications and users of 3D printing and identify ties between the inaccessibility of these tools and existing technology in the classroom.

2.4 Augmented or "Smart" Classrooms

Mixing technology with education yields classrooms that can be "smart", interactive, enhanced, augmented, or ubiquitous. Adding information technology to the classroom over time has seen everything from the inclusion of the computer lab to smart whiteboards and automatic logging of learning metrics. In mainstream education, studies have explored the use of projection, mobile devices, and tangible interactions on student learning and engagement. The high-level themes for classroom technology appear to be engagement, documentation, and tracking.

Engagement in the context of "smart" education usually includes augmenting or outfitting existing learning conditions and objects with intelligent components as a means to try to capture students' interests with the additional appeal of technology and embodied interactions. Augmented reality features heavily in these systems, such as Construct3D where students learn about geometry using a head-mounted display while manipulating shapes with the assistance of their instructor (Kaufmann & Schmalstieg, 2002) or projecting additional information onto tables or surfaces that can interact with tangible components tracked with RFID or fiducial markers (Bodén, Dekker, & Viller, 2011; Bodén, Dekker, Viller, & Matthews, 2013; Bonnard, Jermann, Legge, Kaplan, & Dillenbourg, 2012).

Mobility and immersion are also part of promoting engagement with learning via technology. Radu *et al.* built a tablet-based app that encouraged children to explore math concepts by exploring specially tagged spaces and maps with their tablet camera. Within the app, those markers were then converted to augment settings with puzzles and math problems animated to make the space more interactive (Radu, Doherty, DiQuollo, McCarthy, & Tiu, 2015). And Lui *et al.* demonstrated physical immersion for learning by projecting simulated environments on screens and interactive whiteboards (Lui et al., 2014). The goal of this work was to encourage engagement by utilizing collective inquiry and emulating field research within the classroom, having students explore their digital surroundings and hunt for clues independently before rejoining as a group and showing one another their various findings.

Documentation and tracking in augmented education can be separate concepts or done in tandem. Some examples include systems designed to capture the content of classes, particularly at the secondary and postsecondary level. Before large swathes of learning environments and educational resources were available online, these systems spearheaded digital education by attempting to capture lecture notes, audio, and other content (Brotherton & Abowd, 2004; Friedland, Knipping, Rojas, & Tapia, 2004; Ganoe et al., 2003). Sometimes tracking of course content merged with tracking student data and supporting collaboration, as with Martinez-Maldonado's technology driven classroom eco system. Combining tabletops, individual devices, external sites, and servers, they built a system designed to support individual creation, collaboration in small groups, communication with instructors, and access to course materials. They also built several smaller applications to help support these different intents, like C-mate for mapping ideas and brainstorming, ScriptStorm for cooperatively doing script writing, and Well-Met for managing and submitting group work (Martinez-Maldonado, Clayphan, Ackad, & Kay, 2014). A more passive example of the augmented classroom was an instrumented kitchen built by Hopper *et al.* as a tool for task-based learning. Students would follow recipes in a foreign language in a specially instrumented kitchen that would detect actions to see if students were accurately following task-based pedagogy. As students completed linear steps, the system could track progress and detect problems (Hooper et al., 2012).

The incorporation of technology in special education contexts is similar to approaches and goals found in mainstream education. There are still clear themes of documentation and tracking, but there is a transition from engagement to more explicit technology interventions in the form of assistance. Here, we see educators and technologists designing systems to help students manage their disabilities or stay on-task while capturing their behavioral data for goal setting specific to individual student abilities.

An example of assistance-driven technology in the classroom include devices intended to help students who are low or non-verbal, such as Garzatto & Bordogna's Talking Paper, a system to add a layer of multimedia interaction to paper-based pictographs as part of an augmentative and alternative communication device (Garzotto & Bordogna, 2010) co-designed by children with and without disabilities in effort. The co-design component was intended to reduce the stigma surrounding the use of the system and encourage inclusive interactions. Another example is Chan's use of iBeacons for a context-aware AAC system. The goal of this system was to identify micro-locations within the school building to help build more context-aware responses for students who were non-verbal (Chan, Bai, Chen, Jia, & Xu, 2016).

One of the most common forms of classroom technology focusing on assistance is a scheduling system. These systems are sometimes designed for a single student or for an entire classroom and are used as a smart or interactive replacement for paper scheduling systems. The vSked system, developed by Yeganyan *et al.* is an example of a classroom-wide intervention. This system uses iPads and large vertical displays to track student progress in a special education class with young students who have profound autism. The system is a means for the teacher to see who is progressing well through tasks, to give positive feedback and rewards to students, and to help students track their schedule during the day (Yeganyan, Cramer, Boyd, & Hayes, 2010). On a more individual scale, Fage *et al.* designed a tablet-based system where students with autism or their caregivers can take photos and write step-by-step instructions for later use when completing steps. In this way, students have both a schedule and a linear set of micro-tasks to complete toward larger tasks built and stored on a tablet (Fage, Pommereau, Consel, Balland, & Sauzéon, 2014). More recently, Zheng & Motti have adapted similar scheduling and monitoring systems to work on a smartwatch as a way to make the system both more portable, more discrete, and potentially more socially acceptable (Zheng & Motti, 2017).

Most of the schedule-driven systems described above offer some level of behavioral tracking. Students, instructors, or aides can use the systems to determine if the student is on-task and meeting their goals. CareLog, built by Hayes *et al.* and based off of earlier work by co-other Bowden offers a system explicitly for tracking behavioral data (Hayes, Gardere, Abowd, & Truong, 2008). They worked in cooperation with educators to design a system for capturing behavioral data about students. The system relied heavily on instructor control and the ability to revisit data after the fact, rather than using it in real-time like the scheduling applications. The goal is to track on and off task behaviors in young students with profound cognitive and social impairment and to use that data as a means to identify patterns and trends and to set goals for behavior change over time. In my final studies exploring inclusive learning environments, this technique for tracking behaviors and triggers would prove to be the most useful from an educator perspective. I have extended Hayes' work by exploring these needs in inclusive learning and with older students, specifically young adults with intellectual disabilities in postsecondary education.

This dissertation builds off of "smart" and augment classrooms by contributing a deeper understanding of not just how the presence of technology may be building barriers instead of offering opportunities for students with disabilities, but also revisiting how special educators view the role of technology as a means for intervention and behavioral information tracking.

2.5 Inclusive Education, Universal Design for Learning, and Peer Learning

Access to education for people with disabilities was more or less nonexistent prior to the 1970s in the United States. Students with any number of motor, sensory, or cognitive impairments were effectively banned to homeschooling or received no education at all. As part of the larger trend in civil rights in the U.S., the government passed both the Education for All Handicapped Children Act (EHA) in 1975 and later revised and renamed this as the Individuals with Disabilities Education Act (IDEA) in 1990. This act enforces that everyone has a right to education and that children in particular are to be afforded the individualized education necessary to support their learning regardless of ability. These protections do not extend fully to postsecondary education and they do not guarantee an inclusive learning environment.

Concerns about the ability of teachers to accommodate students with disabilities lead to the longstanding practice of segregated special education. Students with moderate to severe disabilities were often put in “special needs” classrooms with other students with disabilities either in separate classrooms within mainstream schools or in entirely separate special needs schools. This system left students with mild disabilities and undiagnosed learning disabilities in mainstream spaces, ideally seeking and receiving the support necessary to keep up with their peers without disabilities. While a step above simply keeping a child with a disability at home, this segregation and mixed support has contributed to widespread misconceptions about persons with disabilities.

Inclusive or integrated education is the theory of desegregating these learning spaces so students with disabilities can learn alongside their peers. The historical argument against this has been lack of resources and divided attention negatively impacting students without disabilities who must share their instructor and classroom space with students who are perceived as having more demanding needs. Studies have shown that there are few if any negative repercussions for students without disabilities where inclusive education is being implemented effectively and with administrative/system support. Peer learning is an educational technique that is not specific to special education, but it lends itself well to inclusive interactions. Peer learning relies on students learning by teaching other concepts as they master them with little to no intervention or direction guidance from an instructor (Boud, Cohen, & Sampson, 2001).

Multiple approaches have been developed to provide education that is more inclusive to students with a wider variation of abilities. A rising sensitivity to learning disabilities and autism has served to increase interest in practices like Universal Design for Learning (UDL). This is an extension of universal design for accessibility applied to education and it follows three guiding principles: 1) flexible methods of presentation; 2) flexible methods of expression and apprenticeship; and 3) flexible options for engagement (Burgstahler, 2011). Burgstahler provides an in-depth discussion of how UDL principles can be applied in computing education and the ways in which it can support students with a wide range of backgrounds, including students with disabilities (Burgstahler, 2011). The concept of 21st Century Learning incorporates many of these principles and focuses not just on short-term student outcomes, but also the need to plan for future employment with an emphasis on the need to acquire technology skills.

It is a common societal belief that post-secondary education provides more job opportunities with the potential for higher salaries. In a study of students with ID, 58% of all students who attended higher levels of education were employed after completion of their education. This is compared to the 32% of students with IDs who did not receive a postsecondary education (Migliore, Butterworth, & Hart, 2011). For many of these students, a lack of understanding of the decision making process and a lack of self-determination can cause poor career related choices (Dipeolu, Hargrave, Sniatecki, & Donaldson, 2012). An increased skill set in postsecondary education allows students with ID more time and practice making career related decisions that can increase their confidence and decrease negative emotions impeding the decision-making process.

My doctoral research seeks to both build upon the inclusive education practices described here and also to help highlight the existent disparities in access to education and employment. Despite legislation and a long history of special education research, society is still underserving many segments of the student population with disabilities when it comes to technology. I strongly believe this is rooted in lack of understanding, awareness, and consideration for individuals with disabilities in technology as a discipline and as an educational resource. By providing rich descriptions of technology in special education and providing explicit accessibility barriers in technology design, I hope to shed light on this subject and drive interest in addressing these concerns.

3 Methods

3.1 Qualitative Approach

The studies included in this dissertation take many forms, but I have used a primarily qualitative approach. My body of research attempts to address a problem of equal access and to build an understanding of social behavior in the context of technology education. There exist a myriad of quantitative methods and metrics to study learning outcomes and technology performance, but my work seeks to provide a rich description of the relationships between learners with disabilities and the technologies that can serve as aides or obstacles to their advancement in education and the workplace. Qualitative research is the best approach to capture these lived experiences and unpack them because it allows me to provide the necessary context beyond the statistically documented barriers for persons with ID.

Another valuable consideration when selecting my methodological approach was my focus on a special population. People with intellectual disabilities have heterogeneous cognitive impairments and a range of social adaptive impairments that impact the collection and analysis of data from these participants. Variations in physical and cognitive performance make quantitative data difficult to capture with any statistical significance. This can be influenced by individual performance in a lab environment, inconsistent or uninformed self-report, or simply the variance itself as it presents between participants. And, with many special populations, access to participants can severely limit sample size.

Instead, I am relying on rich description and a deep exploration of context to help build a complete picture of the education technology experience for students with ID.

3.2 Ethnographic Action Research

The ethnographic action research approach is a hybrid of traditional ethnography and action research (Tacchi, Slater, & Hearn, 2003). Developed by Tacchi *et al.* while exploring access to information and communication technologies (ICTs) for low-income populations, the ethnographic action research method includes the documentation and deep, situational exploration of ethnography and augments it with a two-stage, cyclical framework to build knowledge from applying action or change.

The first stage is broad research, wherein the investigator immerses themselves in a community and develops a contextual map through qualitative data collection. It helps the researcher understand the problem space while simultaneously building relationships with the stakeholders within the community. Those relationships later allow stakeholders to become informants and contribute both to the direction of the research and to the interpretation of the findings. The second stage is targeted research. Targeted research is a reduction in scope to a subset of the population or a smaller focus in the larger context that can be acted upon and studied in further detail. The cyclical component is an iterative process of planning, doing, observing, and reflecting.

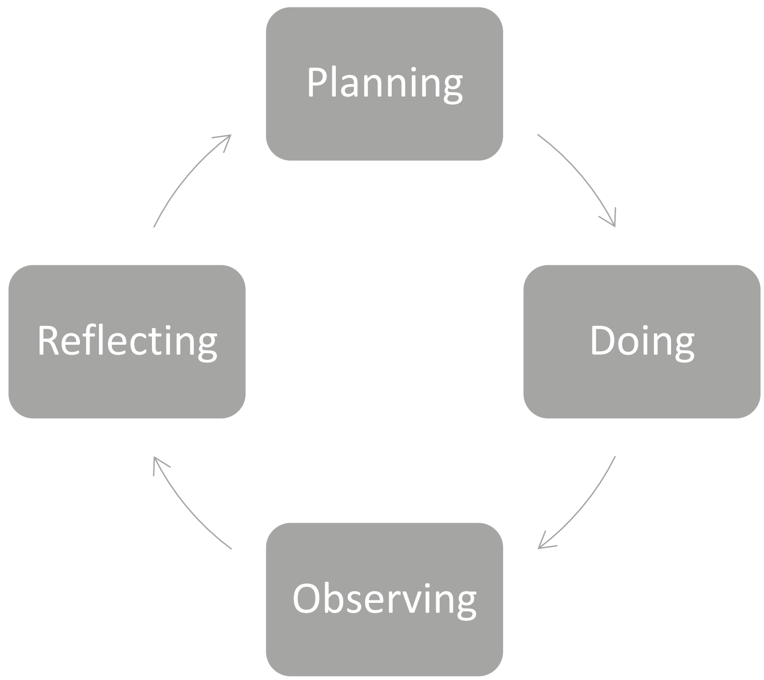

Figure 1. The iterative cycle of ethnographic action research, as described by Tacchi *et al*.

My research uses this framework, combining cross-sectional and longitudinal data collection, stakeholder informed reflection, and iterative study design. This approach enabled me to gain a deep understanding of the context and related problems, incorporate stakeholders directly in the research process, and to take direct action on the societal and educational problems I was studying. I began my broad research phase with a series of studies exploring 3D printing and its potential applications and barriers for populations with disabilities. The targeted phase of my research then focused on the accessibility of 3D printing technology for students with ID in postsecondary education, wherein I planned my own curriculum, participated as an instructor, conducted observations and data collection, reflected on those findings, and iterated on the course. Much of the study design and curriculum was informed by various stakeholders in the space of special education and students with ID, in combination with qualitative data collection and analysis methods described in the subsequent sections.

3.3 Data Collection

Observations: Watching users in-situ is a common practice in HCI research. By viewing behaviors in the wild, we preserve the social and environmental context and we encounter the surprises and failures that are often left out of sterile lab studies. In my early studies, I relied heavily on direct observation, wherein I was a solely an observer and did not engage directly with students.

Semi-structured Interviews and Focus Groups: If you want to know, ask. Gathering perceptions, prompting stories, and reflecting findings back to participants expands one's understanding of a problem space and helps to vet the conclusions drawn from analysis. I leveraged semi-structure interviews with many types of stakeholders, including both educators and students. Focus groups offer similar benefits, but also help to uncover anecdotes that can confirm or refute findings. One participant may present a relevant piece of information in an interview that many other participants would have shared, if only they had been prompted with the right questions. Focus groups have been used in my research to help generate ideas and to find saturation. One or both techniques have been used in every study presented in this paper.

Questionnaires, Journals, and Artifacts: I collected written responses and examined artifacts generated by participants to gain a deeper understanding of what my student participants in later studies experienced. I used student journals to learn more about how students perceived their interactions with each other and with classroom technology. I examined assignments created by student participants to determine where students were succeeding in mastering content and discern where to further investigate potential obstacles. I was able to use these signals as prompts to follow up with students or explore specific topics. I also utilized surveys in multiple studies to gain a baseline understanding of participants' experiences.

3.4 Data Analysis

Grounded Theory: I am a technologist and a researcher, this makes my perspective and perceptions heavily skewed when investigating issues of technology accessibility and education. Furthermore, as I am not a person with a disability and I am not a family member, caregiver, nor close friend to a person with an intellectual disability or any other cognitive disabilities. As such, I am far removed from the lived experience of the students and persons discussed in this study. To help situate myself and my methods, I have consistently used grounded theory and related ethnographic methods to help understand the perspectives of those involved from their own lived experience. My data collection methods reflect this, relying heavily on a mix of observation and interviews. I used open and axial coding, affinity diagramming, and thematic analysis throughout (Merriam, 2009).

Visible Conduct Analysis: In an effort to capture more detail in the classroom, one of my studies also included video and audio capture of students. I have leveraged existing methods surrounding visual and conversational interaction analysis to explore this video data. I asked domain experts in special education and behavioral psychology to help me mutually identify the interaction themes in this space and build a framework for coding this data from their expertise (Heath, Hindmarsh, & Luff, 2010).

3.5 Additional Considerations

Research with Special Populations: When working with individuals with ID, it is important to build safeguards into the protocol design for interviews and focus groups. Special considerations include comprehension and social dynamics. Questions should always be delivered to participants in language they understand and in an unbiased way. Persons with ID may struggle with complex or abstract concepts and so questions must be framed carefully. Due to the social behavioral impairments associated with this diagnosis, these individuals can sometimes be highly acquiescent. This can mean an urge to please the interviewer that may be more pronounced than an in interview with a neurotypical individual. Or, if the participant with ID is given a series of options, they may always select the first or the last option given because it is easier for them to recall that single item than to recall and consider the entire list (Paul, Kleinhammer-Tramill, & Fowler, 2009).

As such, I have taken great care to write questions that do not lead or bias answers and that can be easily comprehended or presented in multiple formats. I spent two semester volunteering in a program for young adult students with ID (see section 7.2.1) and regularly asked for input from educators and stakeholders in this program while designing protocols. I incorporated extra time and multiple modalities to help improve the clarity for participants and to add confidence to the accuracy of their answers. I also implemented means to triangulate findings wherever possible. Combining observations with surveys, artifacts, interviews, and focus groups can be used to reduce ambiguity in a finding.

4 Teaching and Learning Strategies for 3D Printing from Mainstream Education

4.1 Motivation – How is 3D Printing Taught and What Are the Applicable Best Practices from Mainstream Maker Learning?

While 3D printing has existed in various forms for many years, the past decade was marked by a significant decrease in price, improved print quality for consumer-grade hardware, and an increase in free, open source, or low-cost 3D modeling tools. The resurgence of do-it-yourself culture, now framed as "Maker" culture, includes public interest in self-taught programming, novel applications of small electronics, and combining crafts with technology. The use of computer numerical controlled (CNC) milling machines and 3D printers is commonplace in makerspaces, providing custom housing for electronics and opportunities to bridge the digital world with tangible artwork. Enthusiasm from hobbyists began to spread to hacker- and makerspaces, then to community centers and libraries, and mainstream education spaces.

Given its popularity and reasonably low entry point, I chose to explore access to technology education through the lens of 3D printing. The relative novelty of this technology would later allow me to explore learning experiences and differences between students with and without disabilities. My hope was that both populations of students would have limited exposure to this technology and that lack of exposure would help reduce confounding issues of technology access and practice. To get a baseline understanding of 3D printing education for novices, I sought out examples of success and failures from educators teaching this subject to youth without disabilities.

In the study described in this chapter, I interviewed adult educators and youth designers from mainstream education to find out more about their experiences, the obstacles they faced, and the solutions and workarounds they developed to move forward and remain engaged with 3D printing technology. I later used the findings from this work to inform the design of an integrated 3D printing classroom discussed in Chapter 7.

4.2 Methods – Semi-Structured Interviews with Adult Educators and Youth Designers from Informal, Mainstream Makerspaces

My goal for this early work was to learn how mainstream educators were implementing 3D printing for youth learners. My approach included semi-structured interviews and six focus groups with two to four participants each with the goal of gathering experiences from educators and youth. I collaborated with a local tech center to recruit participants and found youth 3D printing designers and adult 3D printing educators from multiple schools. Adult interviews were conducted in person and over the phone. Interviews with children were conducted in small groups with three or fewer students. Each interview or focus group was under an hour and was audio recorded. All participants received modest compensation for their time.

4.2.1 *Interviews with Adult Educators*

My collaborators at the tech center recruited educators (Table 1) who offered 3D printing education to youth. These educators had either taken 3D printer training from the tech center or were staff members at the tech center. I interviewed 7 adults between the ages of 20 and 46. These educators had been working with 3D modeling and/or 3D printing for 6 months to 5 years (avg. 2 years). I collected demographic and training experience information about the educators, the youth they worked with, and the learning environment where they taught 3D printing. We also discussed lesson plans, tutorials, and examples of work created by the educators and their students (see Appendix 11.1).

Table 1. Adult participant demographics: gender, age, occupation, youth level/environment where 3D printing is taught (G: grade, HS: high school, MS: middle school, K: kindergarten), and amount of 3D printing/modeling experience.

P#	G	Age	Occupation	Youth Taught	3D Exp.
A1	M	44	Public K-8, teaches G6 math & social studies.	Afterschool tech club G8.	6 mos.
A2	F	46	Private K-12, teaches G2-5.	Elective tech class.	6 mos.
A3	M	32	Public HS, teaches drafting.	3-part CAD HS course.	5 yrs.
A4	M	28	Public MS, teaches G8 English.	Middle and high school tech teams.	1 yr.
A5	M	30	Program staff at a community tech center.	K - 12 youth members.	4 yr.
A6	M	21	Program staff at a community tech center.	K - 12 youth members.	1 yr.
A7	M	20	Program staff at a community tech center.	K - 12 youth members.	2 yrs.

4.2.2 *Interviews with Experienced Youth*

I interviewed 15 youth between the ages of 11 and 18 (Table 1). These participants had been using 3D modeling and/or 3D printing tools for 4 months to 3 years (avg. 14 months).

These participants had all completed 3D printer training and had 3D-printed projects at the tech center. A few of the children had learned about 3D printing before coming to the center or had access to printers outside the center. Several of these students received training from the adult participants affiliated with the center in addition to other tech center staff members who were not interviewed for this study. I interviewed youth about their experiences learning 3D modeling and printing, how long they had been doing it, and who taught them. We discussed their perceptions of 3D printing and asked them to share stories of successes and failures with printers, as well as the skills they would like to acquire.

Table 2. Youth participant demographic information: gender, age, and amount of experience with 3D printing.

Participant No.	Gender	Age	3D Experience
YB1	Male	14	4 months
YB2	Male	11	6 months
YB3	Male	13	1.5 years
YB4	Male	12	6 months
YB5	Male	13	3 years
YB6	Male	12	2 years
YB7	Male	13	1 year
YB8	Male	14	1 year
YB9	Male	13	6 months
YB10	Male	18	6 months
YB11	Male	18	2 years
YG1	Female	11	1 year
YG2	Female	15	2 years
YG3	Female	11	6 months
YG4	Female	13	1 year

4.2.3 Analysis

All interviews were audio recorded, transcribed and coded using open themes (Merriam, 2009). In total, over 9 hours of audio were collected and artifacts from the community tech center and the various educator teaching environments were documented. Types of artifacts included photographs, digital models, and online resources. Themes I found in the interviews with educators included (1) positive benefits of 3D printing education for students, (2) common obstacles for students designing in three-dimensional space, (3) a need to manage student expectations regarding hardware, and (4) best practices for mitigating failures (lost time, cost of materials, or disengaging students). For youth I found similar themes such as (1) excitement over 3D printing and its potential, (2) points of struggle when mastering 3D modeling tools, and (3) a sense that, while 3D modeling was a technical and challenging skill, 3D printing is becoming a type of digital literacy and everyone should learn how to do it.

4.3 Findings – Peer learning, empowerment, and preparation.

From these interviews, I compiled recommendations for teaching 3D modeling and printing to youth based on concerns and challenges voiced by educators and youth designers. I used the findings from this study to create a curriculum and study design to explore inclusive education practices, discussed in Chapter 7.

I published a more detailed discussion of this work elsewhere (Buehler, Grimes, Grimes, & Hurst, 2015), and I have chosen to include here only two high-level techniques related to teaching 3D printing that I incorporated into my later curriculum design (see Appendix 11.3). The adult educators and the youth designers described the value of peer learning and student empowerment as important components of the 3D printing experience.

4.3.1 Promoting Peer Learning

A common technique brought up by the educators and some students I interviewed was the value of peer learning. Educators described rules and observed behavior in their classrooms and clubs where they encouraged students to teach each other in order to help solidify their learning. *"When I first started teaching I thought it was my job to swoop in right away, but now I make them stronger as designers by letting them grapple with it. ... If you don't really offer to help, they'll figure it out on their own" (A3).* One participant describes how this happens organically, *"I have seen that, where maybe they voice their concerns while they're raising their hand for us and then one of their friends will jump in and say 'oh, that's easy. Here's how... ' " (A5).* Another instructor describes how his students sometimes serve as better teachers than himself, *"The one thing with kids is that they learn more off of each other than they do from me. ... They collaborate and they speak each other's language. ..." (A1).* In answer to a question about how often students help each other, one boy stated, *"Yeah, all the time. Like a person might not know how to get the shape they want and another person will have an idea for how to use a negative shape to get it" (YB3).*

I found team design experiences were an important part of the curriculum for 3D printing education, based on the success stories provided by the educators in the study. Students who are at a similar level in terms of their spatial and mechanical reasoning may be better able to assist their peers who are struggling with concepts related to 3D modeling and printing. The educators using this model described their students as being independent, highly creative in their designs with respect to problem solving, and surpassing the skill level of the material presented to the student group at large. By contrast, educators who did not encourage this instructor-independent behavior frequently described students getting stuck or discouraged. These educators also mentioned that taking the time to help assist these students set back the rest of the group and contributed to lost time—an important concern given the current time constraints of 3D printing.

While the youth did not always actively seek peer-learning experiences, my findings suggest that the youth were open to this idea. The youth I spoke to preferred seeking help from adults to save time, but they made no objections to the idea of helping their peers and shared stories of times when they assisted others. Some participants described attempting to teach 3D modeling skills to their siblings or other family members at home. These impromptu lessons at home were not always successful, but the youth said this was to do with lack of enthusiasm on the part of the family member.

4.3.2 Empowering Students

A key benefit that reinforced students' in their learning described by the educators was the excitement and empowerment students encountered when using the printers. When asked about the benefits of 3D printing for students, one middle school teacher explained, *"I think it teaches them that when you're looking at a problem that there are multiple ways to solve it. … I think that 3D printing really hits on … creativity and problem solving very heavily. It helps them think outside of the box and accomplish things that were not possible. And I think it also does something to excite them about technology" (A4)*. The youth I interviewed expressed a sense of pride at completing a task or solving a problem unassisted by adults.

Many described themselves as master modelers and talked at length about things they would love to build or see happen with 3D printing in the near future. *"We need more of [3D printing] in schools. There's a lot of technology that kids don't know about now… if they get to know it when they're younger, then they can do it when they're older. … If they're inspired by it, they can build something better than it. Getting to know all kind of new technologies, kind of give them some kind of inspiration when they're older. (YB11)"*

Student empowerment was seen by educators as a way to reinforce learning and as a source of excitement and self-determination for students. Both of these issues are particularly salient to students with disabilities and play a key role in later work discussed in this document.

4.4 Contributions – Strategies and Considerations for 3D Printing Education

This study was an early exploration of 3D printing in mainstream education. I was able to publish this work as a preliminary step toward designing my own inclusive 3D printing classroom to explore questions of technology education accessibility for students with disabilities. My findings from this work generated an itemized list of recommendations for mainstream educators looking to incorporate 3D printing into their curriculum design. A truncated list of these strategies from my participants for implementing a 3D printing curriculum and how I have applied those ideas in later studies are listed below:

- *Setup opportunities for success early and often to promote student engagement.* I designed several first-experience assignments that are easy to complete in a short amount of time and can be printed rapidly.
- *Consider the time constraints of 3D printing technology in its current form when mapping out lesson plans.* I experimented with both a 1-hour 3-times-per-week schedule versus a 3-hour once-per-week schedule and have found the longer bock of time is more conducive to a positive class experience.
- *Reduce the complexity of step-by-step projects to mitigate student frustration caused by "missed steps".* The majority of the design tasks I gave to students loosely structured and focus more on creative elements than procedural task completion.
- *Give demonstrations of the design-to-print process to help reinforce students' understanding of printer mechanics.* Students see the printing as early as possible and have the opportunity to see their early designs printed immediately.
- *Balance open-ended assignments with real world constraints to prevent students designing beyond the means of your printer's specifications.* The assignments I gave to students are framed around entrepreneurship, and so the students had to consider the cost of materials and the limitations of their printers as part of their product design process.

5 Exploring 3D Printing in Special Education Contexts

5.1 Motivation – What Can 3D Printing Offer Special Education?

Three-dimensional printing has been touted as a means to promote STEM engagement and retention for students in mainstream education and many of the educators I interviewed in my previously described study echoed this. I wanted to understand how 3D printing could be used in special education. To investigate this, I conducted a two-part study: (1) provide a 3D printer to a secondary special education school's technology classroom and observe its use and (2) interview educators, administrations, and technologists in inclusive learning environments. I found promising applications and interest in 3D printing related to UDL and encouraging youth with disabilities to pursue education in STEM fields where they are sorely underrepresented.

In addition to providing opportunities to students, faculty, and caregivers in their efforts to integrate 3D printing in special education settings, my investigation also revealed several concerns and challenges in accessing this emergent technology. I was able to identify concerns specific to students with developmental disabilities and cognitive impairments and observe techniques used by special educators when working with these students. These findings have helped shape the way I delivered curriculum content in my integrated 3D modeling course and afforded me an introduction to learning strategies for students with cognitive impairments.

5.2 Methods – Observations in Special Education and Semi-Structured Interviews with Faculty, Staff, and Technologists

My investigation set out to gain an understanding of how 3D printing could support special education. The goal was to observe 3D printing in special education and to understand the perceptions of the stakeholders in this space. I conducted interviews and observations at three diverse sites: Site A, a special education school serving students with developmental disabilities including cognitive impairments, motor impairments, or both; Site B, a school serving students with visual impairments; and Site C, the technology services department of a national organization working with blind individuals. I conducted long-term classroom observations and a series of interviews with staff, instructors, and occupational therapists. One limitation in this study was a lack of access to students. Owing to their doubly protected status as both minors and persons with disabilities, I was unable to work directly with the students at these sites.

5.2.1 Classroom Observations

I conducted longitudinal observations at Site A for an academic year, where I attended six sections of an information technology class each week. This course's curriculum taught computer skills, ranging from office productivity to computer hardware and networking. The instructors and administrators of this school were also interested in incorporating 3D printing into their curriculum. In order to help the instructors implement the 3D printing curriculum, I provided the classroom with a 3D printer, supplies, and technical support. The goal was to gather real world stories about 3D printing in the classroom and remove start-up obstacles that might prevent the instructors and students from utilizing this technology. By providing these resources and presenting myself as an expert on 3D printing, this introduced a certain amount of bias to my interactions with these participants. I was not able to access any similar educational settings that had already introduced 3D printing and since the stakeholders at this site wanted to try out the technology, I opted to provide the technology and have attempted to take the introduced bias into account.

Class sections contained between 3 and 13 students, 2 instructors, and 1 to 4 student aides, and lasted 45 minutes. The school administrators enrolled students in different class sections based on the experience level and individual support needs of every student. Thus, students with more experience and lower support needs were placed together and students with less experience and greater support needs were grouped into other sections of the class. I took detailed notes on classroom activities and artifacts such as instruction worksheets, student 3D design files, and 3D printed objects. I remained strictly in the role of an observer during class time, but I conducted debriefs with the instructors at the end of each school day. Debriefs included gathering reflections from the educators about incidents I had observed during the day, to help me clarify the context and perception of scenarios I was recording. The debrief time also served as a learning opportunity for the educators, wherein they could ask for help troubleshooting the 3D printer and I could offer thoughts or suggestions related to operating the printer.

5.2.2 Interviews with Faculty and Staff

Based on my observations and experiences working closely with Site A, I defined a set of stakeholders I perceived as relevant to the introduction of 3D printing in special education. These stakeholders included faculty, staff, and administrators. The stakeholders at Sites A and B gave support to youth students and represented important perspectives in the delivery of curriculum and assistive technology to students in multiple educational settings. At Site C, I spoke with a technology coordinator who provided information on assistive technology related to vision impairments to organizations and end-users of assistive devices.

Table 3. Number of participants interviewed at each site, listed by role.

	Instructors	Administrators	OTs	AT Specialists
Site A	3	3	2	2
Site B	1	1	0	0
Site C	0	0	0	1

In cooperation with my contacts at each site, I recruited participants through email, explaining my research interests and inviting faculty and/or staff to participate. I conducted 13 interviews across three sites all of which were individual, semi-structured interviews lasting 30-60 minutes (Table 3). All the interviews were completed on-site and in-person, except one which was completed via phone call. These interviews occurred after I began my observations at Site A, were guided by the observations I had made, and were staggered across sites and participant types within a month after observations had begun. The interviews were structured around the following themes: software and hardware challenges, student engagement with 3D printing, printer maintenance, safety, intellectual property rights, and time committed to 3D printer use (see Appendix 11.2).

Most participants were not familiar with the mechanics of 3D printing, so at the beginning of each interview I briefly explained how 3D printers worked and I showed 3D-printed objects to the participants to help illustrate the tangible output from 3D printers. These objects included 3D-printed tactile graphics, small models, and working gears (Figure 2). Interview questions and prompts were designed to elicit discussion and further insight on observed themes, but also served to reveal new issues not previously identified. The questions were tailored to the role of the interview participant. An example question for a technology instructor: "How do you manage student expectations?" Questions for technical experts, as another example, sought to uncover the realities of the technology in practical use. For non-technical instructors and therapists, questions posed were designed to illicit perceptions of and uses for 3D printers in their unique environments.

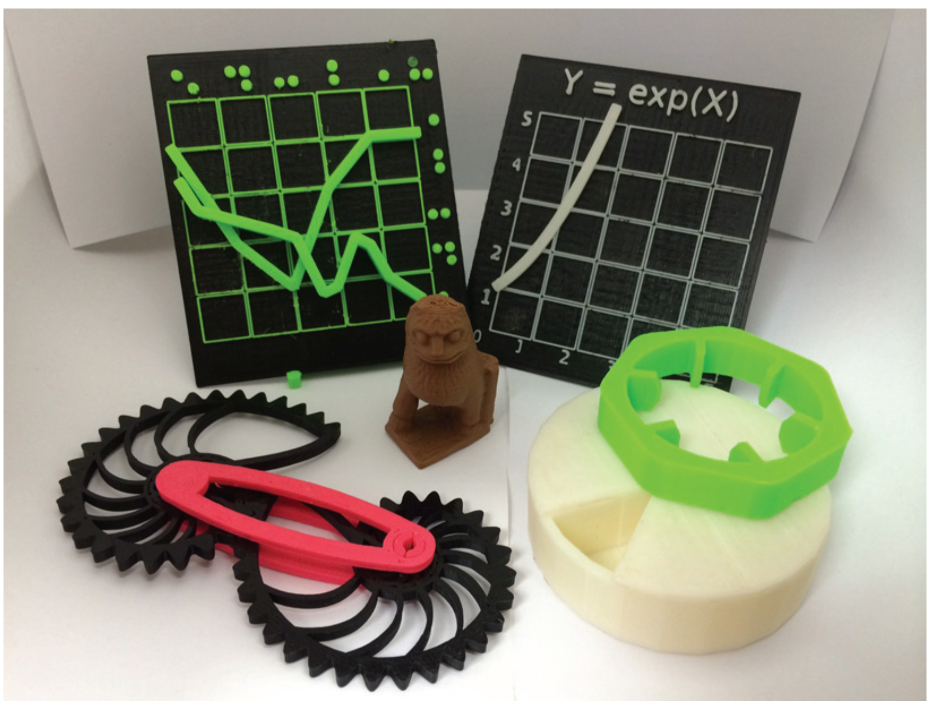

Figure 2. Examples of 3D-printed artifacts including tactile graphics of line graphs, nautilus-shaped gears, a statue replica, rotating pillbox, and bottle cap gripper.

5.2.3 Analysis

I transcribed and thematically coded observations from field notes. This process included two passes searching for high-level themes associated with the expectations, goals, use, and challenges related to 3D printing. A short list of themes surfaced included (1) obstacles to use specific to hardware and software, (2) student reactions of excitement or frustration, and (3) outside interest from other teachers, administrators, students, and staff. This coding helped me to identify themes and stakeholders to further pursue and I used them to inform the protocol design for a collection of semi-structured interview questions surrounding 3D printing in special education. The interviews were also transcribed, coded, and examined using affinity diagramming.

5.3 Findings – Applications for 3D Printing and Accessibility Barriers to 3D Printing in Special Education

By conducting interviews and observations, I was able to gain the perspectives of multiple stakeholders in educational contexts, identify applications for 3D printing technology, and suss out the key barriers to deploying this technology in a special education context. Highlights from this work are detailed below, and the full extent of my findings were published elsewhere (Buehler, Comrie, Hofmann, McDonald, & Hurst, 2016; Buehler, Kane, & Hurst, 2014).

5.3.1 Applications for 3D Printing in Special Education

Administrators and instructors at all three sites described benefits to student education as one of the most important contributions of digital fabrication in the classroom. They perceived the process of learning 3D design and printing as a fount of competencies gained for employability. The creative process before starting a design was described as a problem-solving skill; exposure to CAD software was part of a greater portfolio of digital skills for postsecondary education and future employers. They also felt the accomplishment of generating a physical object, whether it be a gift, a product, or a tool, was deemed an excellent way to build confidence in all students.

For Site A and Site C, 3D printers offered a livelihood. It was suggested that youth could experience entrepreneurship by designing and selling products. This was again seen as a confidence builder, but it had the dual purpose of teaching financial skills.

Manipulatives were also a common topic among administrators and instructors. Manipulatives are concrete objects or materials used to help convey abstract concepts, historically used to teach mathematics (e.g., using blocks to teach counting would be concrete, whereas pictures on flashcards represent semi-concrete resources) (Dunlap & Brennan, 1979). The ability to provide multimodal learning support to students in any classroom setting was suggested numerous times. Participants talked about using digital fabrication to replicate famous works of art, create interactive history dioramas, furnish students with models of geographic features, and offer alternative ways for students to demonstrate understanding of abstract concepts with concrete objects. These suggestions are in keeping with the UDL approach to education.

5.3.2 *Accessibility Barriers to 3D Printing in Special Education*

Provide Accessible Feedback

One significant obstacle I observed for novices learning to use this technology was developing an accurate mental model of the printer. Common problems included not understanding why prints failed, the limits of a given printer's capabilities, and the relationships between troubleshooting techniques and the problems they are intended to solve. Youth designers without disabilities from the previous study also described similar challenges, but described overcoming these issues relatively quickly with practice. Additionally, the youth designers had adult educators evaluating and approving their designs before attempting to print them. In Site A, the technology instructors themselves were struggling to understand what would and would not print while simultaneously trying to contend with a high print failure rate. Their print failure rate was higher than usual early in the school year due to printer reliability issues. As a result, I replaced their printer with a more reliable model, but even with a more typical failure rate, successful printing continued to be a struggle for these educators.

Make Accessible Software

Issues of accessibility were noticeable across types of disability. Upon interviewing the technologist at Site C, she informed me there was no open source 3D modeling software that was accessible to a screen reader. (At the time of this publication, OpenSCAD is now screen-reader compatible, but not optimized for this use.) Observation of the students at Site A and the frustration expressed by the technology teachers at this site highlighted issues of interface inaccessibility. Students frequently clicked on the wrong items and teachers expressed exasperation at counter intuitive features.

The absence of a cutting tool was a concern brought up by instructors and easily observed in student behavior. Not to be conflated with the slicer tool used to prepare a 3D model for printing in layers, the desire for a cutting tool was simply the need to cut away or subtract a piece of the model from itself, like cutting something in half with scissors or extracting an organic shape with a knife. Subtraction in Tinkercad is accomplished by taking an existing 3D object and turning it into a “hole”. To slice an object in half, one must first create a rectangular polygon, convert it to a “hole”, and then stretch and skew the rectangle into a thin plane that the user must group with the object to be sliced. The sliced object continues to behave a single object (i.e., there is a visual gap between the two pieces, but they cannot be moved independently), and so users must then duplicate the object and delete each half to create two independently editable objects. The lack of a dedicated tool and the lengthy and abstract process necessary to arrive at the slicing behavior was beyond the capacity of most students at Site A. The accessibility of these tools should also be considered for end users who have difficulty remembering complex task sequences or have limited short-term memory.

<u>Support Editing Existing Models</u>

One resource that all participants across sites mentioned were 3D model repositories. Existing models offered an opportunity for one-step printing experiences and provided a solid foundation for projects that required only small edits. Stakeholders who were not working directly with 3D modeling often described an interest in having a catalog of 3D models to choose from and being offered a simple tool for making minor changes for customization. A mix of existing tools or minor modifications to existing tools may be enough to support novice users. While there are options for the customization of existing 3D models (such as Customizer on Thingiverse), these tools are limited. Three-dimensional scanning physical objects may offer an easier way to create custom designs, however many current 3D scanners have low resolution or require complex cleanup to make a printable model.

The overall consensus was that a repository of models would offer quick access to tangible learning aides like replicas of art or history pieces (in support of UDL) and an easy way to create an engaging 3D printing experience with reduced frustration.

5.4 Contributions – Value for Special Education, Recommendations for Educational Tools, and Repository Intrigue

I identified obstacles and opportunities for 3D printing in the context of special education, made recommendations for improvements to software and hardware tools for 3D modeling and printing, and provided considerations for special educators looking to introduce 3D printing into their curriculum. I used the lessons learned from this study to design my inclusive 3D printing course discussed in Chapter 7.

This study contributed to increased interest in alternative applications for 3D printing and special populations, including designing tactile resources for learners with visual impairments (Stangl, Kim, & Yeh, 2014; Stangl & Yeh, 2015) and creating bespoke assistive devices for a range of physical and sensory disabilities (Hofmann, Harris, Hudson,

& Mankoff, 2016). I conducted a series of follow-on studies into occupational therapy and 3D printing that touched on accessible 3D modeling tools for therapists (Buehler et al., 2016), teaching 3D modeling to therapy students (McDonald et al., 2016), and the need for a more inclusive culture and toolset for 3D printing as a subset of the maker community. In Chapter 6, I discuss in more detail findings from an initial survey of the largest online community and resource for 3D printing enthusiasts and how the community lacked representation of persons with disabilities.

6 Assistive Technology Design and Exploration of Representation in an Online Repository Community

6.1 Motivation – What Are the Use Cases for 3D Printing for Special Populations and How Feasible Are They for End Users with Disabilities and Their Caregivers?

During my stakeholder interviews described in Chapter 5, two of my participants were occupational therapists (OTs) and they raised a question to me about using 3D printing to create custom assistive technology. I worked with these OTs to create a modified stylus grip for a student with a hand dexterity impairment. The results from this case study spun up into a targeted software modeling tool for non-technical stakeholders seeking to create 3D models for accessibility (Buehler et al., 2016; Buehler, Hurst, & Hofmann, 2014). While working on this, I also conducted a survey of existing AT and accessibility related modifications available in the 3D modeling repository Thingiverse.com. The original intent of these studies was to explore 3D printing for clinical use, however, I also uncovered a pointed lack of representation for persons with disabilities in the 3D printing community of Thingiverse. These studies help to shed light on missed opportunities for people with disabilities in technology fields as both a hobby and a career path. Inaccessible technology education and a societal perception that students with disabilities cannot accomplish technical feats are a clear contributor to underemployment and lack of representation of persons with disabilities in technical careers.

6.2 Methods – Assistive Technology Survey of an Open Source 3D Modeling Community

Based on the successful creation of an occupational therapy aid for a student at Site A, I wanted to know how pervasive 3D-printed assistive technology was in the maker community. The goal of this study was to determine the baseline presence of assistive technology designs and their designers in the subset of makers using 3D printing. At the time this study was published, the Thingiverse.com website was the largest online repository for open source digital maker designs and the website self-reported having over 100,000 user-submitted designs available. To determine the presence of assistive technology, I conducted a keyword-based survey of the existing AT designs on the site and then sent a targeted questionnaire to the designers of the AT items I found.

6.2.1 Keyword-Based Survey of Existing 3D Printable AT Designs

In collaboration with six other researchers, I derived a set of keywords related to assistive technology and healthcare needs (Table 4) that included field-specific terms from the literature and colloquial terms to surface as many relevant designs as possible. I then used a script to query the Thingiverse search engine with each keywork, and multi-word searches were placed within quotation marks to obtain exact string matches.

Table 4. Top 15 keywords that appeared in the complete set of 3D models identified as assistive designs.

Keyword	Frequency
pill (58), pill box (18), pillbox (14)	90
prosthetic (44), prosthesis (17)	61
disabled (14), disability (12), disabilities (10), impaired (1), impair (1), handicapped (3), handicap (1)	42
visual (25), visually impaired (7), visual impairment (1)	33
enable	25
tactile (19), tactile graphic (3)	22
assistive device (11), assistive (9), assistive technology (2)	22
Braille	18
grip	18
wheelchair	17
access (11), accessibility (6)	17
amputee	15
medicine	12
elderly (4), old (3), senior (3), aged (1)	11
cane	10

I, along with my collaborators, refined the key term list after preliminary searches to ensure coverage and added terms that were not initially included, but appeared in design descriptions or comments (e.g., "handicap"). The final list included 173 terms, with 115 yielding appropriate results and 58 yielding none. For our purposes, we defined assistive technology as any piece of technology that is designed to increase, maintain, or improve the functional capabilities of people with disabilities, older adults, or people with chronic health conditions (IT Accessibility Workforce, 1998). Search terms not yielding results included "hearing impaired," "motor impairment," "cognitive disability," "paraplegic," "quadriplegic," "Parkinson's," and "Alzheimer's" despite there being numerous designs that might be described by these keywords.

The search results totaled over 25,000 “things” and I worked with my co-authors to manually evaluate the relevance of each entry and to create a list of AT designs. Each “thing” was assessed in a linear fashion where designs could be eliminated from the list based on relevance as determined by the design title, visual inspection of the design, and additional information in the design description, tags, and/or comments. For each design that met our AT definition, we gathered the “thing” number (a unique ID given to designs on Thingiverse.com), title, designer handle, and the number of likes, makes, and remixes. We categorized each list item according to a set of formal inclusion criteria (Figure 3) and then further open coded qualifying designs by their construction requirements (Figure 4).

Inclusion Criteria

IC 1. Traditional assistive technology products currently available as products or made by therapists: tools for activities of daily living or math manipulatives for people with cognitive disabilities (6% of designs).

IC 2. Accessible media: including tactile graphics with Braille that modeled DNA, atoms, or buildings (11%).

IC 3. Accessories for assistive devices: aesthetic toppers for canes, power wheelchair joysticks, or game controller joysticks for people with physical disabilities (8%).

IC4. Concept designs and prototypes for assistive technologies: creative solutions to accessibility challenges or needs that aren’t currently addressed by existing products, such as a visionary design of a non-surgical cochlear implant for the profoundly deaf or severely hard of hearing, or a heat-based display (4%).

IC5. Prosthetic limbs: prosthetic hands, fingers, or partial fingers for amputees (17%).

IC 6. Tools for medication management: pill-cutting guides or containers for sugar cubes for older adults and people with diabetes (36%).

IC 7. Other design explicitly intended for disabled or senior users: spinner rings for people with ADHD (18%).

<u>Construction Complexity</u>

No Assembly – Ready-to-use items requiring no assembly. Single 3D-printed part (29.8%) or a single laser cut part (0.3%).

Some Assembly – Requires at least some assembly of multiple items. Multiple 3D-printed parts (40.5%), multiple laser cut parts (1.3%), or a mix of 3D-printed and laser cut parts (0.3%).

Assembly and Extra Parts – These items require the assembly of multiple created parts and/or the addition of extra parts that cannot be manufactured with a 3D printer or laser cutter, such as hardware or electronics. Multiple 3D-printed parts plus external parts (27.5%), multiple laser cut parts plus external parts (0.3%), or a mix of 3D-printed and laser cut parts plus external parts (0.0%).

Designs were cross-coded by at least two researchers and disputes about coding were mitigated by discussion with a third researcher. This yielded a detailed landscape of 3D-printable AT designs, but due to the limited amount of information presented in the design descriptions and the designer profiles, I knew very little about the designers themselves and their position with respect to the disability community.

Figure 3. Example designs from our inclusion criteria (IC). IC 1) Right angle spoon for people with limited dexterity. IC 2) Tactile graphic of Yankee stadium. IC 3) Wheelchair mounted environment controller. IC 4) Prototype to convert images to heat for people with vision impairment. IC 5) Prosthetic hand for users with a functional thumb. IC 6) Pill bottle lid with daily reminder label. IC 7) Ironing guide for individuals with vision impairments.

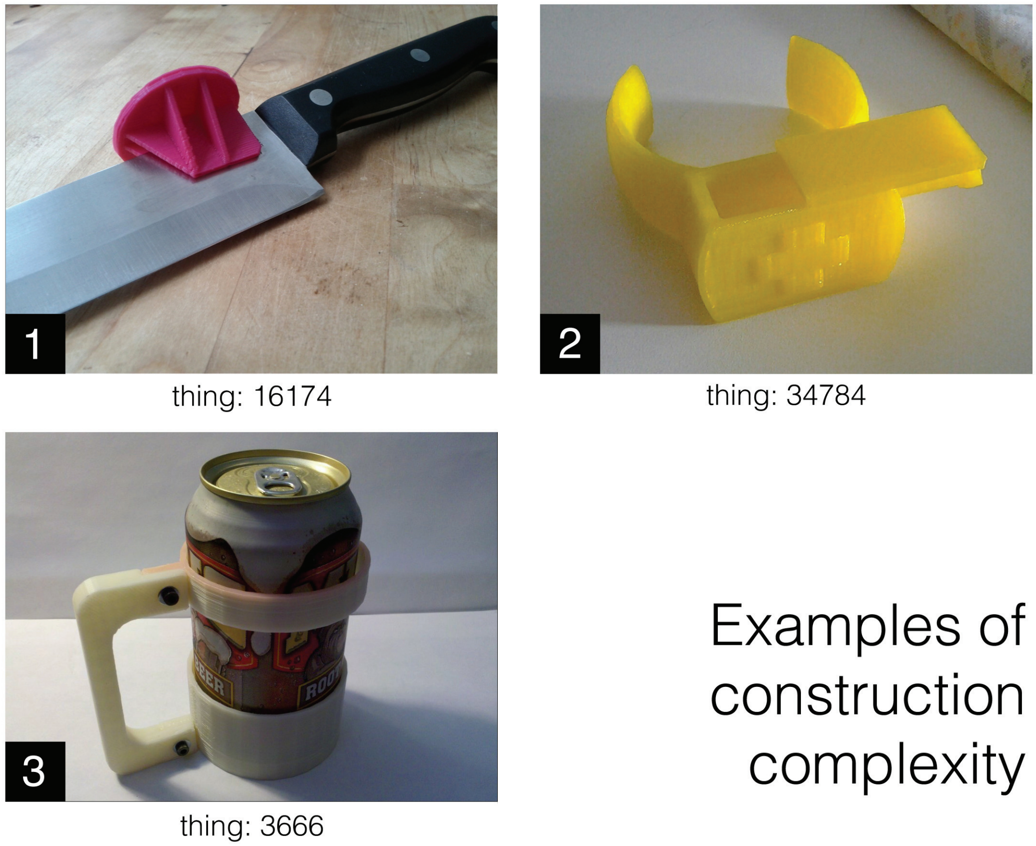

Figure 4. Example items with different construction requirements: 1) knife assistant for limited dexterity (no assembly required); 2) a wearable pill box (some assembly); and 3) cup holder (assembly and extra parts).

6.2.2 Questionnaire for 3D Printable AT Designers

As a second step to gain a deeper understanding of why these objects were being designed and who designed them, I invited the designers of these 3D-printable AT objects to complete an online questionnaire. I contacted 273 designers to participate in the questionnaire and received 70 responses (25.6% response rate) over a two-week period. One respondent was under the age of 18, as such, their data was omitted from analysis and all future statistics on designers pertain to the remaining 69 respondents. Participants were added to a raffle for a $100 gift card as compensation for their efforts. The questionnaire took approximately 15 minutes to complete and contained both closed and open-ended questions. Respondents were asked to provide demographic information and to describe the motivation, process, tools, and outcomes of their designs.

6.3 Findings – Lack of communication, representation, and accessibility.

The survey and questionnaire yielded multiple interesting results concerning the structure of the Thingiverse site and its search feature, the process by which designs are iterated upon and shared, and about the intentions of the designers. The full details of this study are published elsewhere (Buehler, Branham, et al., 2015), but I have included key findings here related to the lack of representation and involvement of people with disabilities in the designer population and design process, respectively. Despite the obvious merits of 3D printing as a means to create AT and the do-it-yourself mentality of the “maker” movement and 3D printing, less than 26% of the respondents were persons with disabilities

6.3.1 Self-reported Designer Demographics

I asked designers for more details about themselves, including information about any disabilities they might have (Table 5), age, occupation, and experiences with 3D modeling and assistive technologies.

Over 48% of designers had a career in a STEM field, including engineers, programmers, and information technology specialists. Fewer than 13% reported health care occupations, such as neurologist or dentist. Students made up approximately 14% of the respondents, and less than 3% of respondents indicated 3D printing expertise as their career. The remaining 14% included a wide range of careers, such as an artist, a realtor, business professionals, and teachers.

The designers reported ages between 18 and 71 with the mean age 37 and 18.8% being over the age of 50. The majority of designers (>76%) reported that they had no disability. The top three reported personal uses for AT were medication management, physical or motor impairments, and learning disabilities (all fewer than 1% of our sample).

Table 5. Self-reported information by disability for designer and intended target user. Respondents could report multiple disabilities, no disabilities, or decline to answer. In some instances, respondents reported that their target user was not intended to be a person with a disability, even though their design fell within our AT definition.

Disability	Target User	Designer
Allergies	1	0
Cognitive	7	1
Coma	1	0
Dexterity	15	1
Elderly	11	2
Learning	2	2
Medication User	14	6
Physical/Motor	23	5
Reading	0	1
Sensory	6	0
Temporary Injury	3	1
Visual	11	1
None	9	53
Declined to Answer	8	4
Multiple Answers	42	8

6.3.2 Motivation for Designs

In order to understand the motivation for designing these objects, I asked questions about why and for whom designs were created. These open-ended questions asked respondents to describe the motivation behind their designs in their own words. I analyzed these responses using open coding with six categories. To further differentiate between these motivation categories I provide brief descriptions of each, along with a quote from one of the respondents.

<u>I Made This for Myself</u>

"I have tendonitis and ulnar nerve damage (repetitive stress injury) and was curious if I could improve the ergonomics of my Magic Trackpad by changing its angle similar to how 'vertical' mice help traditional mouse users with similar wrist/hand problems."

The ability to self-design assistive technology is highly empowering. My questionnaire found that 13 designers created AT designs for their own use. This is particularly significant when considering the high rate of user abandonment in AT, which may be reduced if the end-user has a direct role in the design and creation of their AT (Hurst & Tobias, 2011). While I was encouraged to see some self-designers, this was not as common as I had hoped. Increasing the number of self-designers might be accomplished in the future by increasing awareness of making assistive technology or by providing more accessible software and hardware tools for the creation of these designs (Hurst & Kane, 2013).

<u>I Made This for Someone I Know</u>

"My aunt came to me for help, because she was having difficulty moving my uncle around whenever he had mini seizures. Since he had a walker anyway, she needed a way to push him around when he can't help himself."

Making an object for someone the respondent knew was the most common response with 24 designers indicating that they created AT designs for friends, family members, and other acquaintances. This included designs for aging parents, partners with disabilities, and children. Given the range of disabilities reported, it is difficult to say with confidence why more disabled users were not self-designing. Possible reasons could be the perceived difficulty of 3D modeling and fabrication, leading end-users to approach friends or family members with existing engineering or computer skills. Depending on ability, end- users may not have accessible design tools to create designs, but we did not fully explore this in our questions.

A close relationship with the end-user enables these designers to have a discourse. The designers would, in theory, be familiar with the user, task, and environment. These are key factors in creating a positive user experience. A dialogue with the intended user has the potential to design for the individualized needs of specific disabilities. Ways to promote this dialogue could include community efforts to pair designers with end-users or finding ways to support this connection through the design sharing web sites more implicitly.

<u>This Was a Personal Challenge</u>

"I want to create useful objects. This bracelet I've designed, can contain medications, a note with dangerous allergens, or emergency phone numbers for elderly ill people."

Thirteen respondents reported their motivation to create the design as wanting a personal challenge. They described wanting either a test of their ability as a 3D designer or they simply identified what they perceived as a need and created an object to fill that need. These respondents likely did not talk to anyone with the disability they were attempting to address, and they had to guess preferences. This begs the question, should these types of AT designs be encouraged and/or dispersed? With little or no AT training and no contact with the end-users, it is difficult to say what if any value these items have to the disability community at large.

<u>This Was Required for a Class or Competition</u>

"I created this design for an undergraduate course I was taking in engineering design. The concept was to create a pillbox that could keep track of medication usage throughout a week (or weeks)."

Only five respondents indicated that they created and uploaded their designs as part of a contest or as required by a classroom assignment. The pitfalls of the previous category apply here, as well. As with the designers creating items for others, for these projects to have any impact it might be more appropriate to pair contestants and students with individuals with disabilities or related support organizations. In this way, students and contestants can still tackle interesting design challenges, while bolstering the applied outcome of their projects. This might improve designs and increases visibility for accessibility issues.

<u>This Was Part of a Research Project</u>

"I did my Masters thesis designing and printing objects for two children with blindness to help them in school and see if having a 3D printer in school is a good resource."

Only six respondents indicated that they participated in research and/or development as their occupation and that this was the motivating factor in the creation of their design. Open source sites like Thingiverse present an excellent opportunity to the academic and research community to share their work, as these respondents have. I hope to see more research labs creating and open- sourcing their designs in the future to help spread awareness of the possibilities of building AT and to advance these designs with end-user input.

<u>This Is Not Intended for a Disability</u>

"Creating adapters to join different products that fulfill the same use, but utilize proprietary measures."

Despite keywords, descriptions, and our inclusion criteria, eight respondents indicated that they did not perceive their design as targeted to a person with a disability. Examples of this perception included the appropriation of pillboxes as anything-goes storage containers or understating a dexterity aid as simply "useful". These examples are an interesting mix of universal design issues and "Accidentally AT" objects. This may be indicative of an issue of the visibility of disabilities in the maker community at large.

6.3.3 Construction Complexity as a Barrier

We observed a diverse range of construction requirements for items in our dataset, with close to 70% of all items requiring assembly. Construction requirements are an important consideration for adoption as these can impact the cost, difficulty of assembly, and time required to build the technology. For example, single- part designs are likely faster and less expensive to produce than designs consisting of multiple parts, and it can be manufactured using only one machine. Single part designs are also attractive, as they only require the end user to control the fabrication machine, increasing the likelihood that those with limited abilities will engage in making AT.

Designs that require assembly and additional parts may offer more complex support, but the effort and materials required for assembly may deter some individuals from attempting to make them. For example, many of the prosthetic hands found on Thingiverse require significant assembly and specific external parts that may reduce the likelihood that the target user would undertake this project. However, the fact that a bottle opener only requires a single part to be manufactured and that it is “ready-to-use” after printing increases the chance that an end user would make it (Figure 4).

Given that the majority of designers did not have disabilities themselves and many were not working directly with a person with a disability to create their designs, this means that even well-meaning contributions to open source assistive technology may be inaccessible to the very people they are intended to benefit. This speaks to the larger struggles of individuals with disabilities in terms of their self-determination, society’s perceptions of disability, and the accessibility of technology design tools and their resulting products.

6.4 Contributions – Lack of Representation of and Communication with People with Disabilities in 3D Printing Culture

More than half of our respondents reported that they had no formal training in 3D modeling and personal fabrication tools. This is in keeping with the current wave of 3D-printing tools being targeted to novice users. Several respondents described themselves as self-taught, learning techniques such as 3D modeling by watching videos on youtube.com and experimenting with open-source design tools. While this finding suggests these activities are not just for professionals, I observed that the average designer has a technical background.

The majority of respondents were members of the STEM and health care community, with fewer than 36% reporting occupations outside of hard science or technology fields. While many of these designers claimed no previous experience with modeling tools, it is important to recognize that 3D modeling, 3D printing, and personal fabrication have roots in engineering and that the formal skills of an engineer may supplement their informal use of these tools. This might indicate a need to encourage a wider variety of people with differing skills to utilize rapid prototyping.

Out of a group of 69 designers creating assistive designs, more than 76% of the designers reported that they had no disability themselves and less than 1% had any formal training in assistive technologies. There is clearly room to extend more support to alternative users, both in creating accessible tools and helping to democratize this technology for a more heterogeneous group of end-users.

Judging from the distribution of designers in this study, people with disabilities are not well- represented in the current make-up of 3D designers and makers. This is not to say that the engineers and technologists lending their skills to the AT cause are unwelcome. However, this further emphasizes the underrepresentation of persons with disabilities in technology. Educators in STEM and the technologists creating these tools need to consider and incorporate persons with disabilities when designing, building, and teaching novel software and hardware.

Actionable steps to support this goal might include simplifying tools, creating alternative design interfaces, or providing a new delivery system for tutorial information. Technologists should consider the abilities and goals of these potential AT-makers and work with them to uncover best practices for fabrication tool design.

7 Deep Dive into an Inclusive Learning Environment for 3D Printing in Postsecondary Education

7.1 Motivation – Can an Integrated Classroom Environment and Adapted Learning Materials Ameliorate Obstacles to 3D Printing for Special Populations?

At this point, I have presented studies focused on 3D printing in mainstream and special education. I have also briefly explored the applications of 3D printing for special populations and found that, while there are many ways 3D printing could be used to support people with disabilities, the population of people doing this in practice was small and the designers involved were predominately persons without disabilities. A theme woven throughout these studies has been the value of 3D printing for persons with disabilities combined with a lack of accessibility and support. Despite the potential benefits of 3D printing, people with disabilities were not significant participants in this trending technology. In my final studies, I attempted to tackle these issues of support and access by creating my own class built on the learnings I had gathered from other educators and designers and tying those lessons back into my higher-level theme of access to education technology and employment.

As an outsider and observer in my earlier studies, I was unable to control for many variables. I could not keep on top of hardware and software problems because I was not always present. I could not dictate teaching practices or content for students. And, in the special education classrooms, there were strict limitations on my ability to interact with students as they were minors with disabilities making them a doubly protected population. I was able to circumvent many of these issues by creating and teaching my own inclusive classroom at the postsecondary level. At this stage my ethnographic action research approach transitioned from the broad observation phase to the targeted and iterative phase (Figure 5), by planning, participating in, observing, and reflecting on my own course.

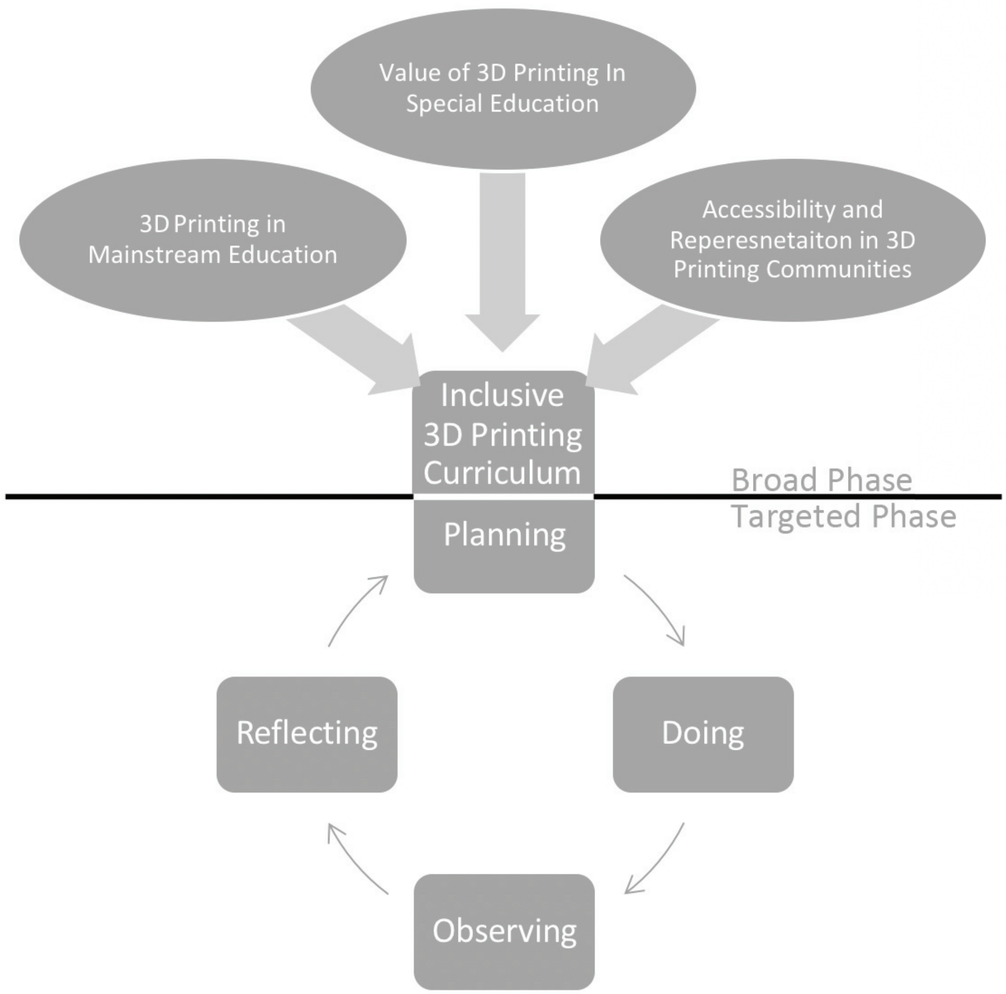

Figure 5. Methodology diagram illustrating the transition from broad ethnographic observation to targeted action research.

The UMBC campus hosts an inclusive, postsecondary certificate program for young adults with ID (SUCCESS) aimed at providing students with an integrated campus experience while teaching independence and employability skills. I partnered with this program and the university's entrepreneurship center to create a novel course combining 3D modeling and printing with aspects of finance, design, and social good. The course was offered in the spring for three years, and it consisted of half neurotypical undergraduates and half young adults with ID enrolled in the SUCCESS program. Based on my prior collaborations with both special education institutes and mainstream educators, I identified topics and techniques to teach 3D modeling and printing skills to novice users. I included activities designed to support concepts of repetition, positive reinforcement, and personalized learning.

7.2 Methods – Observations, Artifact Analysis, and Video Data.

7.2.1 Participant Observation of Inclusive Education

The goal of this study was to explore inclusive and integrated learning of technology in an environment that could act as a middle ground between an uncontrolled but contextual field study and a highly controlled but less contextual usability lab. By observing and iterating on this classroom environment, I was able to explore barriers to learning through the lens of a relatively novel technology, while exploring the use of inclusive education at the postsecondary level as means to support students with ID.

In preparation for this study, I also spent two semesters working in cooperation with the SUCCESS program as a teaching assistant in a first-year seminar course. From this experience, I identified several techniques to carry-over into this study including the use of teams to promote engagement, leveraging peer learning and teaching, and reducing misconceptions and stigma surrounding students with ID. Many of these techniques overlap with valuable strategies I identified exploring potential paradigms for 3D printing education and the majority were implemented in my course design. My long-term relationship with the SUCCESS program and my role as an assistant and instructor in these courses transitions me from an observer to stakeholder. This transition in role is part of my ethnographic action approach and brings with it the benefits of additional context and the biases of being an actor in my own field research.

7.2.2 Design and Iteration on an Integrated 3D Printing Class

For this study, I conducted an integrated, postsecondary course on 3D modeling and printing. This course was taught as a three-credit hour course during spring semester for three years. Each year the participants changed, as did the class size. I also adjusted components of the curriculum to help accommodate the increasing enrollment and incorporate changes from my observations in previous semesters of the class.

During the first semester, the class met three times per week for one hour and had six students with intellectual disabilities (five female) and six undergraduate students without disabilities (two female) between the ages of 18 and 27 (Table 6). Students worked in pairs on design and printing tasks, sharing a single monitor/CPU and a single mouse. I split my time as an instructor with another PhD student, alternating teaching time and observations. When not teaching, the second instructor along with two other researchers, acted as observers or assistants to the students in class (e.g., to replace an absent team member).

Table 6. Participants in the integrated 3D printing course. Students with intellectual disabilities are marked ID and teammates without ID are marked UG for undergraduate status. *Participant ID6 did complete a consent form, thus only observations and no demographics were recorded.

Part. #	Age	Gender	Part. #	Age	Gender
ID01	24	Female	UG01	20	Female
ID02	25	Female	UG02	20	Female
ID03	26	Female	UG03	27	Male
ID04	27	Female	UG04	21	Male
ID05	26	Female	UG05	22	Male
ID06	*	Male	UG06	18	Male

In the second semester, the class met one time per week for a two-and-a-half-hour block and had seven students with intellectual disabilities (three female) and seven undergraduate students without disabilities (three female) between the ages of 18 and 26 (Table 7). As in the previous semester, students worked in pairs on design and printing tasks, but this time each student had access to a monitor/CPU. At different points during the semester, I also introduced additional mice per work station and a time-based pop-up reminder system to reinforce turn-taking. The 3D modeling component of the class was held in a traditional computer lab and the 3D printers were kept in a separate, smaller lab space from the first semester. My role was primarily that of an instructor with another PhD student present to help conduct observations. There were also as many as four additional observers and/or assistants available to act as researchers or help the students in class (e.g., to replace an absent team member). One of these four assistants included a student with ID who had taken the class in the previous year.

Table 7. Participants in the integrated 3D printing course. Students with intellectual disabilities are marked ID and teammates without ID are marked UG for undergraduate status.

Part. #	Age	Gender	Part. #	Age	Gender
ID07	24	Male	UG07	18	Male
ID08	23	Female	UG08	26	Male
ID09	24	Female	UG09	19	Female
ID10	23	Male	UG10	26	Male
ID11	24	Male	UG11	26	Female
ID12	24	Female	UG12	22	Female
ID13	23	Male	UG13	21	Male

The final semester, the class continued to meet one time per week for a two-and-a-half-hour block. Enrollment in the course included eight students with intellectual disabilities (five female) and eight undergraduate students without disabilities (one female) between the ages of 21 and 63 (Table 8). Students again worked in pairs on design and printing tasks, with their own monitor/CPU and the 3D modeling component of the class was held in a larger computer lab to accommodate the extra students. The 3D printers were still kept in the separate, smaller lab space from the previous two semesters. During the final semester, I was primary instructor and there were two student assistants working in the classroom during the semester.

Table 8. Participants in the integrated 3D printing course. Students with intellectual disabilities are marked ID and teammates without ID are marked UG for undergraduate status. *Participants ID16 and UG16 did complete consent forms, thus only observations and no demographics were recorded.

Part. #	Age	Gender	Part. #	Age	Gender
ID14	25	Male	UG14	23	Male
ID15	24	Female	UG15	21	Male
ID16	*	Female	UG16	*	Female
ID17	26	Male	UG17	23	Male
ID18	26	Female	UG18	25	Male
ID19	27	Female	UG19	25	Male
ID20	25	Female	UG20	63	Male
ID21	24	Male	UG21	26	Male

7.2.3 Data Collected

Throughout each semester, observations were collected by myself and other researchers and documented as field notes. Students maintained a daily class journal in addition to their assignments. Journals were intended to record the day's events and allow the students a space to reflect on what worked well and what did not work well during design activities. Student assignments were collected and/or documented by myself and other instructors/researchers, including written assignments, drawings, 3D models (.STL files), and physical 3D prints.

7.2.4 Classroom Setup

Students met in a lab with all of the resources necessary to design and print objects. Based on the experiences described to me by the 3D print educators I interviewed (Chapter 4), I chose Tinkercad for the design software and purchased Printrbot Simple Metal printers (one printer per team each semester). Students were encouraged to use the lab computers, but several installed modeling and printing software on their personal laptops. Course information was disseminated through a public-facing website that students could access from outside the classroom.

7.3 Findings – Inclusive Learning Helps Address Some Barriers, but Technology Accessibility and Social Dynamics are Still Obstacles

Table 9. Iterations on inclusive course design and observed outcomes.

Semester	**Strategy**	**Outcome**
1 – Shared lab space.	1 computer per team, mix of team and individual assignments.	UG pay no attention or refuse to let ID students work on team projects.
2 – Divided lab space; technology-interventions.	Introduce individual computers, move to a split lab environment. Try to force turn-taking and cooperation with technology.	Sometimes students work together, sometimes not. Nobody uses dual mice, nobody adheres to pop-ups.
3 – Divided lab space; human-interventions	No technology intervention, but sometimes human intervention.	Worked about as well as the previous semester. Decided to show video to educator to see what the focus should be.

My analysis revealed five concepts: (1) relationships between students and technology, (2) integrated classroom dynamics, (3 & 4) software and hardware support concerns, and (5) suggestions for educators. I describe each concept below and provide a brief discussion framing these ideas in the larger context of accessible technology education and societal inclusion of persons with intellectual disabilities in school and work environments.

7.3.1 Integrated Classroom Dynamics

By leveraging an integrated environment, both sets of students received educational benefits. I did identify some snags in the collaborative process, but overall ID students working as peers with their undergraduate (UG) student counterparts promoted learning, confidence, and mutual understanding. I discuss some of the highlights in the subsections that follow.

7.3.2 Establishing Working Relationships

Due to the short class time, it took several weeks for students to establish comfortable working relationships with their partners. Over the course of the semester, students became more comfortable helping and communicating with their partners as they became more familiar with them. The working relationship between UG01 and ID03 led to positive social exchanges in which UG01 could correct mistakes without causing any tension. To contrast this with another group, ID01 would regularly ask for assistance from an instructor rather than their partner (UG04), who was frequently disengaged from the class.

7.3.3 Turn-Taking

I observed that the UG student in a group would take control of the computer and do the "driving" during the learning experience while the ID student watched but did not participate. I suspect this behavior was a mix of misconceptions about ID student abilities and a desire to complete steps quickly and efficiently. This behavior ultimately disempowers the students with ID and reduces the impact of their class time. As instructors, we addressed this behavior with a mix of gentle corrections and suggestions, such as, *"How about letting [ID02] do that? She has used [Google Drive] before."*

Turn-taking behavior was also promoted through assigning every student the same in-class assignments and homework. While students were encouraged to work with their partners during the class period, every student was responsible for submitting an individual assignment. An additional benefit of assigning work this way was that less independent students in the class were able to work their way through complex tasks and assignments with a partner who was able to support them.

Technology-driven interventions to promote turn-taking had essentially zero impact on the students. When students were afforded two mice for a single computer, they quickly found that whomever used the mouse with more direct force was able to control the cursor and any cooperation or competition in using the mouse receded into single-mouse user behavior. For the time-based pop-ups, we found that at best, students ignored these pop-ups and continued working in their existing input driver/observer dynamic. At worst, the pop-ups caused distractions and caused individuals or teams to go off-task.

With persistent oversight and correction, we were able to persuade pairs to split their time more evenly. Constant reminders and supervision were necessary to enforce this behavior and sometimes lead to uncomfortable interactions between partners who had highly heterogeneous levels of engagement and/or ability.

7.3.4 Motivation, Outside Factors, and Attendance

Both UG students and students with ID occasionally came to class disengaged as a result of events outside of the classroom. While UG students would grudgingly get on board for classwork, it was more difficult to motivate the students with ID and sometimes this could not be accomplished at all inside the shorter 50-minute class periods of the initial semester. Sources of disengagement that we observed within the classroom included completing repetitive tasks, struggles with printer failure, and issues of personal pacing. UG04 would occasionally lose interest and start playing with his phone or browsing the Internet while his partner completed tasks. There was one instance where UG06 became noticeably upset because two prints had failed during one class period.

Absenteeism was another big issue. Many of the students with ID traveled significant distances to arrive on campus and a harsh winter causing school closures and dependence on family members for rides during inclement weather colluded in severely limited attendance. UG students missed class less frequently, but their absences caused more disruption. Without the UG students, students with ID who counted on their partners for reminders or support during assignments would sometimes shut down. We, as instructors, were available to help these students, but we did not have the close bonds with these students that they had with student peers and so our guidance was not always received with enthusiasm.

We tried to mitigate issues of motivation by offering short, medium, and long-term rewards both inside and outside of class time. A short-term reward might be allowing a student to pick the music in the lab if they progress through two or three steps in an assignment. This method was frequently used with ID06 who often came to class disengaged. An example of a medium-term reward was allowing the student to choose a 3D model that could be printed during class time and giving it to them as a reward for meeting their goals by the end of the session. A long-term reward that was more popular with the UG students than the ID students was the option to come into the lab for free time where they could use the printers for extended prints and projects outside the scope of the course. UG04 in particular was interested in gaining access to other types of 3D printers and would occasionally stay after class to learn additional information. We found that these strategies helped to keep students motivated.

7.3.5 Collaborative Problem-Solving

A benefit of the structure of the integrated classroom setting was that ID and UG students alike had access to multiple resources to aid them when working through a problem. This included partners, peers in other groups, as well as the course instructors. Students regularly consulted with their partners and with other students in the course before asking for help from the instructors. These student explanations in combination with instructional materials supported universal design for learning by providing multiple mediums and multiple explanations of concepts. For students helping to answer questions, this also provided the opportunity to develop their communication skills.

7.3.6 Technology as a Confidence Builder

At the beginning of the semester, only one or two students with ID were willing to experiment or show unguarded interest in exploring the software. This could be attributed to being in a new setting, feeling pressure or intimidation while working with another student, or the common tendency of some novice users to exercise restraint in technology because they fearing causing harm or inability to recover from errors. We noted that after learning to set up a 3D printer, start a print independently, or create a 3D model, students appeared more confident in their technical skills. This was observed through students performing technical tasks on their own while asking fewer questions. A team that showed a significant shift in dynamic was a pairing between ID01 and UG04. At the beginning of the semester, ID01 was eager but reserved and frequently tried to confirm steps with their partner and with the instructors. By the end of the semester, ID01 would still approach the instructors, but would declare scenarios rather than ask questions. Instead of *"I think I'm ready for the next step?"* she would take the action on her own and only approach us for complex problems, *"The printer is broken again."*

7.3.7 Skill-Building Toward Employability

While we do not expect all of our participants to become 3D printing experts, the students did practice and gain skills toward employability. They learned specialized skills related to the process of creating and printing a 3D object, which may have some application in the field of engineering or manufacturing. There also gains in more generalizable skills related to employability. Examples include: computer literacy, such as navigating through a file system; problem-solving by way of practiced troubleshooting; collaboration and communication skills improved through group work; and customer service skills practiced by offering print services to campus students and staff.

The majority of the students demonstrated a keen interest in making money, which was a theme woven into the curriculum of entrepreneurship. The students expressed interest in selling their designs on campus and one student, ID03, inquired about opportunities as a paid lab intern working as a 3D printing assistant in a future semester.

7.3.8 Technology Challenges

As I have mentioned previously in this document, 3D modeling and printing comes with many challenges and growing pains with contemporary tools. Rather than reiterate this list, I have selected a few issues that I feel are specific to the population of new designers who have intellectual disabilities.

7.3.9 Sign-in Issues

As part of the course structure, students were required to turn in written assignments via Google Drive and to complete their 3D modeling in Tinkercad. Students experienced many issues logging into these systems causing frustration and delays.

We tasked students with creating and keeping track of their own user login and password, but this proved too troublesome. We encouraged the students with ID to document this information themselves both to protect their privacy and to support their independence, however, several students struggled to remember their credentials or locate the documentation for those credentials. If a student repeatedly failed to provide correct credentials, the site triggered a 30-minute account lockout. In the constraints of the shorter 50-minute classes, this was detrimental to productivity. This was still a considerable timesink for the longer block classes. In these cases, students would have to try to recreate their work from a previous class on by designing on their partner's account.

Using Google Drive was less difficult than Tinkercad, as access to this service was through students' university login information. The students with ID were more likely to have this password documented somewhere and it proved easier to reset in the event of a complete loss. Alternatively, students could create a starting document in their partner's Drive and copy it to the appropriate location at a future date when the password issue was resolved, thus reducing delays related to replicating existing work.

7.4 Contributions – Social dynamics, failed turn-taking, and an overwhelming data set.

While my iterative changes were able to mitigate many of the barriers related to resource management and our classroom model helped to leverage peer learning to improve individualized learning, there were still issues of social dynamics and turn-taking that were not well addressed. I did capture, very clearly, that a simple time-based or input-controlled technology intervention to promote more cooperative team learning failed and that I needed a better understanding of the role of the technology itself versus the social dynamics between the students. I was also able to capture a significant and, in fact, overwhelming amount of data for deeper analysis to answer these questions. I had acquired two semesters worth of video and audio data to review and a set of cursor data that could be used toward training an intelligent design or tutorial interface based on mouse movement.

8 Identifying Roles for Technology in the Inclusive Learning Environment

8.1 Motivation – Taking A Deeper Look At The Interactions Between Students And Interactions With Technology

The motivation for this final study focused on vetting the findings and contributions from the previous chapter and identifying the gaps and opportunities for future research in the space of inclusive technology education. In my previous study, I was unsuccessful in my efforts to promote turn-taking and engagement by using technology as a means of mediating team behavior. Going into this final study, I wanted to look more closely at those team interactions and determine if the areas I had identified as problems were, in fact, true barriers to education and what other techniques or approaches might help to mitigate them.

For example, my early assumptions focused on the amount of time each student spent using the mouse. For some teams, I saw power dynamics between students impacting their learning outcomes, but even very unbalanced teams sometimes had positive outcomes. I summarized themes and surfaced examples of behaviors I was focused on and reflected them to domain experts. This was done to provide external validation and clarity, in addition to exploring potential solutions.

8.2 Methods – Open analysis, semi-structured interviews with special education experts, and visible conduct analysis

8.2.1 Preliminary Review and Open Video Analysis

In my previous analysis, I identified concerns related to both the accessibility of the technology being used in my classroom and in the disparities in turn-taking and engagement within student teams. The goal of this final study was to bring in external perspective to vet the areas of concern I had identified and determine how technology might be used to improve inclusive education, rather than hinder it.

For the final two semesters of my inclusive 3D printing course, I captured video of the classroom during lab time. During the second and third semester, I placed cameras at a bird's eye view of the room, one on each end of the class (Figure 6 and Figure 7). During the third and final semester of the course, I also implemented team cameras for a handful of sessions recording pairs of students working together. These cameras were either situated in front or directly behind students and could capture utterances between students (Figure 8) unlike the classroom-wide cameras there were only able to capture visuals.

Figure 6. Overhead view of the integrated 3D printing computer lab from the front of the room. This screenshot helps illustrate that despite high-fidelity cameras, video coding is still difficult.

Figure 7. Overhead camera view of the 3D printing class from the back of the room. This is a traditional camcorder with lower-fidelity. Coding this footage was easier, but still lacked audio signal and a clear view of on-screen interactions.

Figure 8. Example screenshot from head-on video showing a team of two students working together. The video is captioned with UG21 speaking to ID21, "If you want that shape you gotta do that one. Here, I'll let you--you do it."

Facing an overwhelming amount of video data from two semesters and over a dozen teams, I opted to utilize a video analysis technique detailed by Heath *et al.* in *Video in Qualitative Research* (Heath et al., 2010). Using my prior analysis of deliverables and observations, I reduced the number of teams I would focus on to a smaller subset. I used a combination of self-reported experience and the quality of team-based assignments to narrow my scope to three teams that represented a range of positive, neutral, and negative outcomes from my perspective as the lead educator. Having scaled down to just three teams, I reviewed video pertaining to those teams and coded along themes of interaction (positive or negative) and engagement (on or off task behaviors). I then isolated representative video fragments to discuss my observations and themes with domain experts and used the video fragments as probes for exploring student interactions and the role of technology in special education. Finally, I conducted a deeper interaction analysis of my video data based on an expert-driven schema I derived from my domain expert interviews in order to search for significant trends between students, technology, and positive or negative interactions therein.

8.2.2 Semi-Structured Interviews with Special Educators and Behaviorists Using Video Fragments as Prompts

I interviewed six special education and behavioral specialists with experience working with students with developmental disabilities (Table 10). These participants were recruited via snowball sampling and most respondents had previously worked for the same regional medical institute affiliated with the Site A school discussed in Chapter 5. Each individual had between 4 and 12 years of experience working with children and/or young adults with developmental disabilities in formal or informal educational contexts. All of the participants had some experience with intellectual disability and formal special education environments.

Table 10. List of participants interviewed on observable interactions and behaviors in special education, includes age, gender, job title at time of interview, and years of experience working with special populations.

PID#	Age	Gender	Current Job Title	Exp.
SE1	28	Female	Behavioral Analyst	12
SE2	27	Female	Assistant Teacher	4
SE3	26	Female	Student Coordinator	6
SE4	29	Female	Behavior Associate/Clinical Aide	7
SE5	30	Female	Teaching Assistant/Job Coach	6
SE6	29	Female	Behavioral Technician	5

During semi-structured interviews, I asked each participant questions about their background in special education and their experience working with students with disabilities. I also asked about current uses for technology in special education settings and about the types of behavior these individuals might want to capture, record, or intervene upon and how they currently do this. After getting a baseline sense of their experience and approach to behavior management in educational contexts, I then showed the participants three video fragments. Each fragment was five minutes long and I asked the participants to focus on a specific team for each one. The first and second fragment were of the same class session from an overhead vantage point, but focused on two different teams (Team 08 and Team 12, see Figure 9), and the third fragment was a head-on video of a single pair of students (Team 21, see Figure 8).

Figure 9. Team 08 (left) and Team 12 (right) are circled in red. In Team 08 shows UG08 controlling the mouse while ID08 points at the monitor. Team 12 shows UG12 with mouse control pointing at the screen while ID12 looks on.

The only framing I gave for the video fragments was the structure and topic of the course I was teaching; I did not provide any details about my perceptions of positive and negative behaviors. For all three fragments, I asked the participants to watch for any behaviors they found interesting and to comment on anything they, as educators or behaviorists, would have intervened on or made an effort to reinforce if they had been present. After each clip, I asked the participant about their perception of the interaction between the students, if it was a positive or negative interaction and why, and I asked them to describe anything they would have done or changed about the scenario to improve it.

For the last stage of the interview, I asked each participant to describe their wish list for technology in special education settings. For participants who did not have an immediate answer, I constructed an example using some of the answers they had given me earlier in the interview to help prompt them to think of creative ways technology might help with inclusive or integrated learning environments.

8.2.3 Expert Informed Video and Conduct Analysis Coding (Substantive Review)

From the interviews, I derived a video coding scheme (Table 11) to capture the behaviors the educators marked as significant (positive or negative impact) to interactions between students and other parties (peers, teachers, etc.). I then began coding each team's video from the entire semester using this coding scheme. This coding has highlighted patterns in behavior (for individuals and teams) that indicate potential flags and sequences of events leading up to positive or negative behaviors. As a final step, I have taken those code-able flags and sequences and mapped them to existent technologies that might serve to detect and either mitigate or support behaviors, based on their desirability.

Table 11. Positive and negative codes and definitions, based on domain expert interviews.

Positive Codes	
Code	*Description*
Gesturing	Both students in a team are engaged with assignment, while one or both students are making a hand gesture while the other watches.
Modeling	One student demonstrates or models how to complete an action to their partner.
Praise	Any participant gives praise to a student or team.
Re-engagement	One student is not engaged and their partner completes an action to bring their partner back to engagement.
Talking (Within Team)	Both students in a team are talking to each other about the assignment.
Turn-Taking	Any voluntary exchange of an input device (mouse or keyboard) between students on the same team.
Negative Codes	
Code	*Description*
Attention-Seeking	Student seeks attention from someone other than their partner.
Closed Posture	One student moves their body or computer such that it reduces their partner's ability to engage. This includes blocking one’s view or taking away a resource or device without consent.
Distraction	Student stops paying attention to partner and computer, looks elsewhere, fidgets, etc.
Fatigue	Student stretches, yawns, appears to be in micro-sleep, or otherwise exhibits low energy body language.
Interruptions	Teacher, aide, or student outside the team interrupts the team.
Talking (Outside Team)	Social/off-topic talking to anyone who is not their teammate.

I have applied this revised coding to the full set of videos for the purposefully sampled set of three teams from the expert interview fragments (Teams 08, 12, and 21). More data exits in this set, but the teams I have selected represent a range of behaviors I saw repeated in other teams. As such, I am still able to provide a deep discussion of the types of behaviors that were flagged as most notable by my domain experts and to discuss how different technologies could be applied to these behaviors and would generalize within my specific classroom setting and beyond.

8.3 Findings – Visible Indicators of Interaction Change/Quality and Can Be Used to Explore Technology-Driven Learning and to Capture Behavior Data

8.3.1 Open Coding of Classroom Video

In my initial coding of the classroom video (see Appendix 11.4), I began by coding samples of teams from different days and assignment types. For example, I would code the behaviors of students as teams and as individuals on lab days when assignments consisted of team work versus individual work. I also coded samples of class assignments that emphasized computer work versus low-fidelity design work such as drawing. Most of my coding centered around themes of turn-taking, talking, and attentiveness, and each theme had several smaller, but quite complex issues of sub-theme coding that proved difficult to define and manage.

I defined turn-taking as a visible exchange of control over an input device, such as a mouse or keyboard. While this was easy enough to identify visually, it was clear that this did not capture the more finessed concepts of mutual engagement and learning. Some teams had a different dynamic, wherein the partner who was more familiar with the mouse or who had better coordination would complete the 3D modeling actions with input from their partner. Or the exact opposite, where the student whose skills were more senior would not touch the mouse at all, but instead give the more junior student full control over the mouse and modeling activities and acted instead as an advisor or guide.

I added a code related to on or off task behavior to supplement the lack of clarity surrounding turn-taking. However, without capturing conversational detail, it was not always clear when to apply the theme and the subsequent coding became inconsistent. Talking was relatively easy to identify, but without clean audio of what was being said, it was difficult to attribute utterances between students to on or off task behaviors and whether or not conversations happening outside of the team were social or for learning. It was clear, however, that students who were not talking to anyone were often struggling, off-task, or both.

Attentiveness was the trickiest of my early themes to define. I initially tried to constrain this to gaze, wherein a student is attentive if their gaze is on their partner, an active instructor, or the work at hand. The assumption that intentional gaze was the same as attentiveness was unrealistic and not easy to consistently apply. Students with ID may need more breaks than their peers, have difficulty concentrating for long periods of time, and can often have body language that might appear disengaged to a neurotypical audience. Fidgety, stretching, or yawning in students with ID did not necessarily mean that they were not engaged with their partner or paying attention, making it difficult to identify when this particular behavior was negative.

After these hit-and-miss revisions and recoding attempts, I recognized that I would need to be more selective in the number of teams I coded, the length of video I chose to code, and how I structured my coding. Using a sampling approach for video and audio coding (Heath et al., 2010), I identified specific teams and video fragments to review. I then reviewed these fragments with special education domain experts to revise and refine my coding structure.

8.3.2 Themes from Educator and Behaviorist Interviews: Coding Behaviors

As described in my methods, I conducted semi-structured interviews with six domain experts using video fragments as probes to help better understand the shortcomings of my coding structure and to reduce the burden of coding the entire collection of data. With these experts, I discussed the positive and negative behaviors they observed, the reasoning behind labeling those behaviors as positive or negative, and what, if any, action they would have taken if they had been present during the scenario they viewed. We also discussed the use of technology in special education environments and how technology could be leveraged best in an ILE. Findings from the domain experts fall into two categories. The first set of findings relates to the viewing and discussion of the video fragments, and the second set relates more specifically to technology.

From the video fragments, domain experts gave me specific suggestions regarding what behaviors to track in my coding and whether or not they felt these behaviors were positive or negative. These behaviors are part of a more complex process that many special educators use called Antecedent-Behavior-Consequence Model (ABC) (Miltenberger, 2012). To help a student or individual with ID get the level and type of support that will benefit them, special educators must collect data (usually through observation) about the desirable and undesirable behaviors of that individual. These behaviors are goaled upon, aiming to reduce the frequency or number of occurrences for undesirable behaviors and increase the desirable behaviors. Once the behaviors are identified, the educator must then carefully examine the events leading up to the behavior, the antecedent. This is then used to help identify the process leading up to behavior before it starts and mitigate it in the future. Lastly, consequence is the action that will reinforce the appropriate behavioral change. I was able to incorporate antecedent and behavior flags into my revised coding scheme as positive and negative interactions.

<u>Behavior Tracking</u>

The majority of the educators valued some way to track behavior over time. This can be used toward behavior modification goals, learning goals, or safety. They indicated wanting to know the frequency and/or duration of certain behaviors. They were most interested in self-harming behaviors, which were not prevalent in our student population, but that as educators these participants had a lot of experience with. They were also interested in tracking how much time was spent on or off task as part of a reward system.

"I have tracked behaviors as far as self-injurious behaviors, aggressive behaviors, verbal disruptions, non-verbal disruptions. We would initially collect the data with [a] form which we would use to define and track the behavior and assign a consequence. Then we would track the time of the day, the frequency of the behavior, environmental factors, and anything that preceded it. Then we would develop a program to help correct or change [the behavior]." (SE2)

Positive Interactions

Educators pointed to mutual talking, mutual gesturing, and sharing control over the computer as indicators of positive behaviors. Open or facing postures, where both students can see each other and their computer desk, were considered positive. They also indicated students who paid attention to their partner's engagement level and who worked to re-engage their partners were providing positive interactions. They also advocated for on-task partners explicitly or subtly modeling positive behaviors for their partners to emulate as being positive interaction markers. Periodic, but selective and non-disruptive, praise from third parties like other students, aides, or teachers was also considered positive.

SE3 speaks at length about positive interactions she observed Team 08 engaging in. *"...In the beginning part where he [UG08] was in control of the computer. She [ID08] was constantly pointing at something and then it looked like she was telling him to do something. He would even at times confirm what she said by pointing as well and pointing at the same thing to make sure. Then my favorite part was the fact that he scooted over and gave her a sense of autonomy over using the computer too. He even continued to give his opinion by pointing and saying, like their communication was constant which I think makes it really positive."*

Action: For students who are heavily dependent on praise and reinforcement, frequent verbal praise from a partner or an authority figure. Do not interrupt students who do not need regular praise or who might be too derailed by real-time praise—instead, praise these individuals after activities are done.

Negative Interactions

These consisted largely of positive behaviors being absent. No mutual talking or gesturing. Body language or postures that block or obscure the screen or the assignment from one partner. Lack of attention, wherein one student is focused on the assignment and does not seem to have awareness or interest in their partner's engagement level and makes no effort to bring their partner back to on-task behavior. Third parties interrupting without then working to re-engage distracted students, such as aides or teachers bumping into chairs or having conversations near a team that then causes one or more team members to go off task. Lack of turn-taking or sharing of mouse and keyboard control, even in the presence of communication. And the educators also noted that interactions where the student without a disability completed a task or assignment on behalf of the other student, rather than modeling or explaining the behavior was also negative, as it reduced the independent action of the student with the disability.

Team 12 was often highlighted as a team where the undergraduate partner was unaware of their partner's needs and engagement level, SE1 discusses how that lack of awareness leads to negative behavior on the part of the student with and an overall negative interaction between teammates. In the video clip, the student with ID fidgets and looks around the room, seeking to make eye contact with a passing teaching assistant while her UG partner works in silence: *"So, she's [ID12] kind of looking for that extra attention again by moving back and forth, staring at her [teaching assistant] for a little while. She [ID12] might be fidgeting her hands just because she wants attention, or she just has a sensory need to move her hands. … You can see [the teaching assistant walking by] – most* *of the students that I've had, [if] they're in range of where you're looking, then [they seek] negative attention. Also … the other student [UG12] is not engaging her like she [ID12] needs to be. She's [ID12] doing this because she feels she's bored and no one is giving her the attention that she needs. She wants to be engaged in the work also. So, some of the behavior come from the partner not making an effort."*

Action: As discussed earlier in the document, public praise for students modeling positive interactions, work to re-engage the off-task student, implement a reward structure for on-task behavior, and/or offer a change of scenario based on individual student needs, frustration level, and attention span.

The third stage, the consequence, mapped more specifically to what types of interventions and support systems we could build supported by technology. For each positive or negative behavior, an educator can choose to support, intervene, or ignore the student or students. A few examples of these scenarios:

Positive Behavior; Support: A student who has completed a difficult task requiring considerable concentration is rewarded with a break.

Positive Behavior; Ignore: A student is on-task and being productive. While this is positive behavior, interrupting them to give praise or feedback could derail their progress, so simply monitoring is the better course of action.

Negative Behavior; Intervene: A student is sleeping or showing a similar strong physical display of disengagement, the educator should come over and ask why they are not working or why they are not helping their partner.

Negative; Ignore: A student may be off task, but their off-task behavior is subtle like checking a phone or reading an unrelated website. There is a good chance that their partner or a neighboring student will re-engage them, so giving the students a little space and they may take care of the problem themselves while building social value.

<u>Support</u>

For both cooperative and individual work, educators suggested that positive behaviors should be rewarded. The most frequent reward is verbal praise, but other means to reward or support positive behavior included food rewards (edibles) and activity incentives (free time or computer time). By reinforcing positive interactions and on-task behavior, students learn to be more independent in completing these activities going forward.

Prompted to describe support for positive behaviors, SE4 describes verbal praise and gives examples of other rewards. *"A lot of praise like I know, I can think of one [former student] … he struggled a lot. … I think once we started, for him verbal praise worked a lot. We would cheer him on and it was like immediately aware of he was doing [well]. He also liked edibles, because he was on like a very strict diet for weeks. He would get a skittle or something like that, which would encourage him. He is like I don't know what I'm asking for, but I know when I ask it, you will give a skittle so.*

Then [another former student] that liked to rip things. We actually gave her a ripping bag. It had clothes, paper, different texture things she could rip. She struggled with communication… when she communicated, she would get given something [to rip]."

Intervention

Intervention was a very nuanced subject for the educators. In the context of self-harm or other volatile and disruptive behaviors, educators advised immediate physical intervention. But for less disruptive behaviors like fidgeting, off-task, or non-compliance, educators preferred redirection and non-authority figure interactions. They suggested partners of off-task students work to re-engage their partners as a first step. Then having an aide or teaching assistant publicly praise an on-task team and compliment their behavior. As a last resort, they recommended having a teacher or aide intervene directly with the students in a series of escalating approaches. Intervention starts by asking the off-task student to re-engage with their assignment, then offering an incentive for a short-term completion of on-task behavior, and the most extreme intervention being a removal of the student from the situation, such as a walk or a bathroom break to give them a temporary change of scenario.

Several educators discussed the value of peer-led interventions, and SE1 gives a good example of intervention and re-engagement as observed with the Team 21 fragment. In it, ID21 is showing signs of fatigue and attention-seeking. Instead of ignoring this behavior, UG21 encourages his partner, he attempts to keep him engaged, and he models behaviors to help his partner in a mostly positive interaction. *"He's [ID21] not bored, he's probably struggling. See that he's [ID21] a little engaged when he [UG21] helped him with the shapes and now just looking a little tired, it's been a long day. Now he's [ID21] frustrated because it's not working and of course the attention from [UG21] is going to help him to get his work. .... And now he's [ID21] looking for validation, he probably already knows what it is [the right answer]. He got distracted, he wants to be engaged ...*

. [UG21 redirects ID21's attention to his monitor] ...he [UG21] is still trying to engage him while he do his work. He's [UG21] really engaging him and helping him understand information so he can do it on his own."

8.3.3 Themes from Educator and Behaviorist Interviews: Technology Roles

Technology-specific findings ranged across three stages or levels of use. The first and most requested technology in this space was transitioning tedious behavioral data documentation and analysis to an easier digital format. This did not necessarily entail full automation, and I will discuss this further momentarily. The second stage was leveraging existing technologies to nudge students as a means of reinforcing behavior change. For example, sending a small message to an on-task student as a positive reward or sending a message to a neighboring student to re-engage an off-task student. The third and final stage or level of technology intervention was ubiquitous data capture, but this was deemed the most difficult and unlikely space for technology despite the desire for the behavior.

<u>Discrete Data Collection</u>

The most sought-after technology solution educators wanted was a means to collect data on student behavior that was not disruptive. Most of this work is currently done using analog techniques, such as physical counting clickers and paper sheets. At the end of the day or week, these tallying systems are then manually entered into a spreadsheet to help track behavior change over time for students. Educators wanted ways in which this data could be collected discretely, with or without the immediate supervision of the educator.

Action: Suggestions and ideas included manual entry on a mobile application, camera vision using video data, classroom sensors, or wearables.

Nudging

Some, though not all, of the teachers liked the idea of delivering positive reinforcements or stimulation directly to students. This included ways to replace disruptive fidgets or other behaviors by substituting sensory or stimulation needs with a device. And, in the case of positive reinforcement, rewarding students with direct messages of praise via the computer or as prompts to help re-engage students (either delivered to an engaged partner or as a direct engagement with an off-task student).

Action: Suggestions and ideas here included wearables, augmenting existing stimulus objects (e.g., fidget cubes or spinners), and visual or sound interfacing from computers to prompt engagement.

8.3.4 Expert Informed Coding Scheme and Video Analysis

After revising my coding scheme to incorporate the positive and negative flags from the ABC model described by my domain experts, I then applied this coding scheme to the three teams from the example video fragments. Myself and a second coder completed multiple iterations of coding a subset of video for each team to ensure that we had a clear understanding of each code, its definition, and if any additional codes or exceptions needed to be added to the schema. Once we reached agreement, the remaining video for all three teams was coded. The coded videos were collected from six class sessions from each of the final two iterations of the course. Video were limited to the lab component of the class period (ranging in length from 25 to 85 minutes) and the total volume of footage was over 7 hours and 35 minutes in length. For each session, video was captured from two positions and then analyzed individually for each team. As such, the total time coded is multiplied by two for the camera angle and then by three for each team's analysis—approximately 45 hours of coded time.

The coding showed a consistent correlation between my perceptions of sampled team and individual performance and the positive and negative interaction characteristics identified by the behavioral experts. High engagement was tied with teams I had deemed to be high and medium performers, and low engagement was observed from the team sampled for low performance. Each team and each individual had a unique set of traits and patterns, but these patterns were consistent throughout the video analysis. The following are notable patterns and characteristics I identified with examples from teams.

<u>High Mutual Interaction and Low Distraction</u>

Students from teams I identified as moderate to high performers had higher levels of mutual engagement and lower levels of distraction. The students on Team 08 spent the highest amount of time mutually talking and gesturing while working and had the most frequent turn-taking actions. These two students averaged 47 minutes of mutual conversation and close to 16 minutes per session gesturing toward each other or in reference to their work. They traded turns or controls an average of 11 times per session. Each student from Team 08 also had low levels of distraction, with both students averaging 10 minutes or less of time spent distracted in a session and each burst of distraction in any given session only lasted a few moments (Figure 10). By stark contrast, Team 12 spoke to each other and engaged in mutual gestures an average of just five minutes per activity during a session and only took turns twice across all six documented sessions.

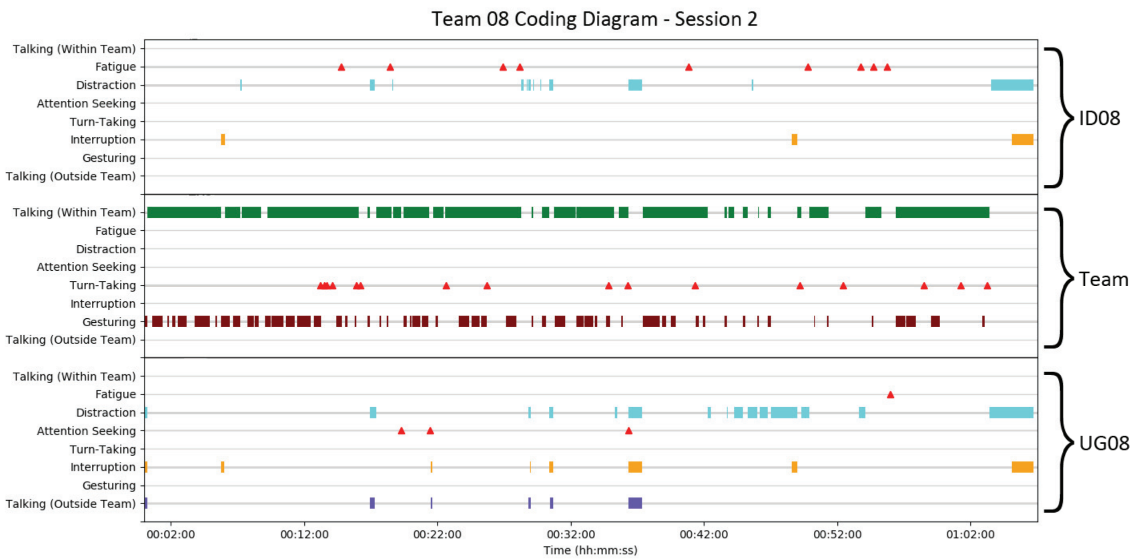

Figure 10. A coded session for Team 08 shows high rates of mutual talking, gesturing, and turn-taking with very low instances and durations of distraction.

Lulls in mutual conversation or gestures seemed to proceed moments of distraction for individual students from all teams, but these lulls had a more frequent impact on students with IDs. There is a clear pattern of gaps in mutual engagement actions and an uptick in time spent distracted, though this is not the sole indicator of potential distraction.

Frequency of Fatigue

I found that students exhibiting fatigue were likely to fall into a distracted behavior pattern and that fatigue occurred most frequently toward the end of the lab session. Both undergraduates and students with ID demonstrated fatigue, though students with ID exhibited this behavior more often. Team 21 was a good example of fatigue and distraction. For this team, ID21 liked emulating his partner's actions and liked being engaged. His partner (UG21) did not usually take advantage of class break time to leave or use the restroom and, since he did not leave or stop working, ID21 would stay and keep him company. In Session 3, there is a clear pattern of ID21 becoming fatigued and that fatigue increases over time (Figure 11). After nearly every fatigue marker for ID21, there is a closely following period of distraction that is then mitigated by mutual conversation initiated by UG21. As the session draws to a close, fatigue markers appear every few minutes, indicating ID21's waning energy and patience for classwork. If ID21 had taken the break offered to him (seen as the interruption at roughly minute 36:00), he may have been refreshed and more able to stay on task for the second half of the lab.

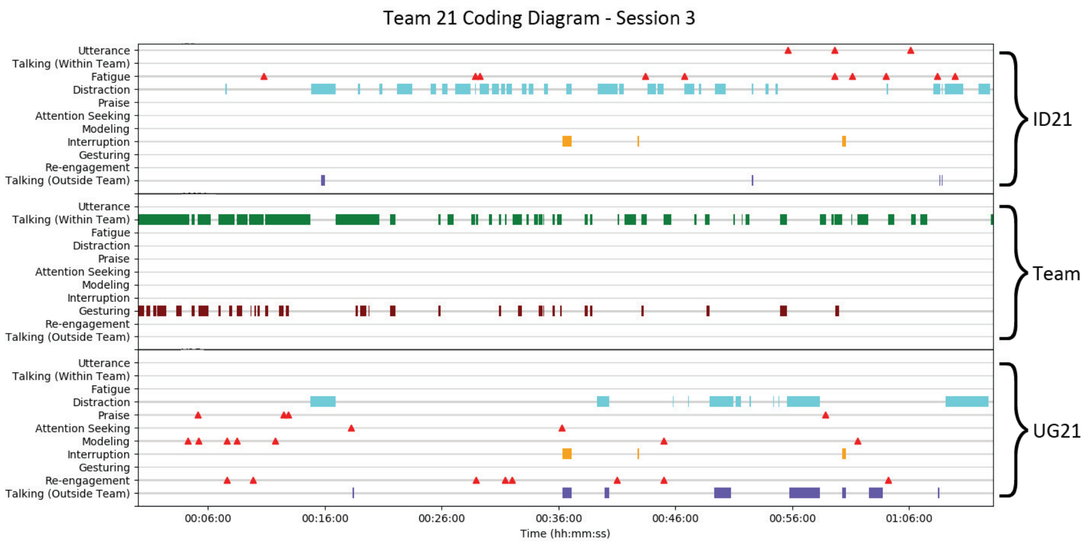

Figure 11. Diagram of video coding session for Team 21. Increases in distracted time for ID21 appear when he and his partner are not engaged in mutual discussion. This also shows fatigue triggering distraction and more frequent fatigue as class continues.

<u>Ignoring a Partner, Distraction, and Attention-Seeking</u>

One of the goals of the inclusive course was to encourage positive social experiences between students, but not all students were comfortable interacting. Students I had identified as having a poor working relationship and lower performance on course materials often had more negative interaction codes and exhibited fewer positive behaviors. Closed body posture and talking outside of the team were common negative interactions for the sample of low performing pairs. The undergraduate student in Team 12 demonstrated closed body posture in multiple sessions and also engaged in regular discussion outside of her team with another undergraduate student who sat nearby (Figure 12). Her partner's (ID12's) codes, meanwhile, light up with a mix of distraction and attention-seeking behavior throughout the session.

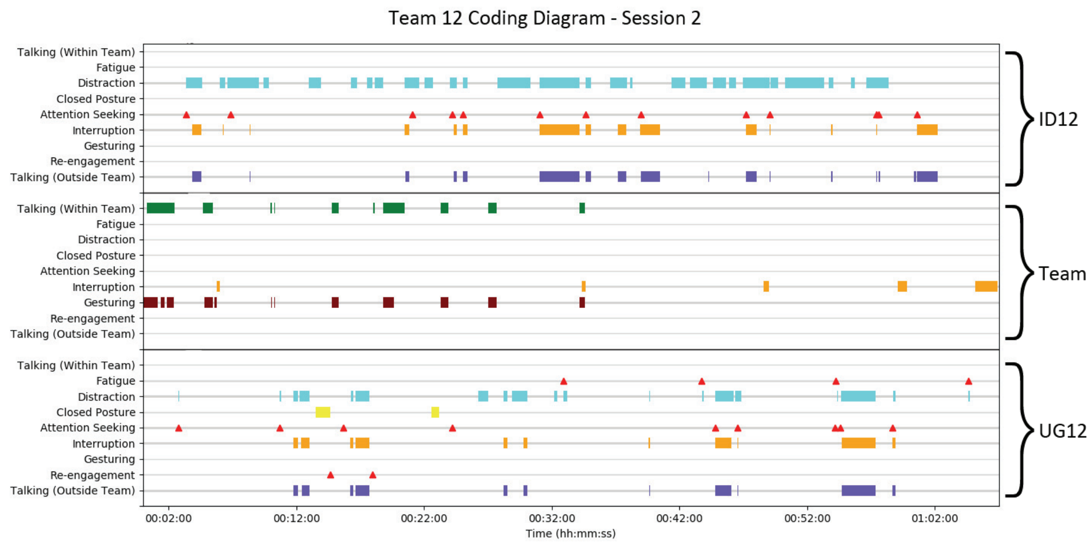

Figure 12. Team 12 demonstrates distraction alongside lack of mutual talking. UG12 has multiple codes for closed posture and talking outside of team that align with distraction for their partner.

Throughout the semester, ID12 showed repeated signs of needing more engagement and sought attention through a mix of behaviors, many of which were negative or distracting. Within a single session, ID12 would try and fail to capture her partner's attention by interactions such as asking questions, mimicking behavior on a separate computer, and leaning far into her partner's workspace. In turn, UG12 would sometimes give brief answers to questions, but often ignored her partner and would turn her body or her whole monitor away. This response may have stemmed from a lack of comfort or confidence working with a student with ID, and ID12's habit of invading personal space may have been perceived as a social violation by UG12.

Lacking engagement, ID12 would otherwise engage herself with sensory stimulation like fidgeting, off-task distractions like her looking through her cell phone, or seek attention from other students and teachers. ID12 sought attention at a rate two times higher than any other classmate and averaged more than 10 instances of attention-seeking behavior per session. UG12 was much more likely to ask other UG peers questions about assignments than to discuss them with her partner and was most comfortable asking the instructor for help, clarity, and feedback. Given her desire to engage with people outside her team, she also engaged in a high rate of attention-seeking behavior, averaging five instances per session. By comparison, ID08 only sought attention once (and only in the absence of their partner), UG08 engaged in attention-seeking behavior two times, ID21 and UG21 representing the neutral performance pair sampling had six and two occurrences, respectively.

Educators and Aides as Interruptions

Something I did not realize as a stakeholder, but later identified with the insights provided by the behavioral specialists, was my role as an interruption. In an effort to be available and more closely approximate the special education environment where individual students might have access to one or more personal aides in the classroom, I often walked around and dropped in on students to check on their progress. These interruptions by teachers (myself and co-instructors) and aides corresponded with bouts of distraction for one or more teammates. In some instances, on-task students would be completely derailed by our check-ins and would require active re-engagement interactions from their peers to get back on task.

The coded data supports the advice I received from the special education experts—effectively, only interrupt or intervene on a student when necessarily. Individual students may benefit from praise and engagement, like ID21, but others are easily derailed and the negative impact to their productivity deeply outweighs the effort to provide support, as was the case for ID12.

8.4 Contributions – A Coding Schema for Identifying Positive and Negative

With input from domain experts, I was able to refine my video coding scheme to identify behaviors that I, as an educator, had perceived as impacting my students' success. These behaviors also map to positive and negative behaviors described by special education and behavioral domain experts as significant to the process of behavior modification known as the ABC model.

With multiple passes and small adjustments, I was able to achieve high interrater reliability on my coding scheme. The raw data remains for several other teams across both semesters, however, I was able to demonstrate identifiable behavioral patterns, relationships between student interactions, and provide observable interaction characteristics that correlated with student performance in my classroom. I also consider my full collection of video and audio information to be a valuable data set that can be leveraged using the coding scheme I have provided, or used as pilot training material for either crowdsourced coding of ABC data or as a means to train computer vision, deep learning, or similar AI to more accurately identifying behaviors for support or intervention, thus reducing the burden on educators in class. Despite my familiarity with my own students and the daily proximity, there were many moments I simply failed to notice. While a trained domain expert may be more sensitive to these interaction behaviors, there is still a high workload for any individual educator to monitor students in a busy environment and there is a pointed lack of student aides present in postsecondary education. Applying these technology techniques could help with personal goal setting, such as ABC, but also provide educators an opportunity to adjust their lesson plans based on data.

The special education domain experts also offered many insights into how current technology could be used to support or augment the best practices in special and inclusive education for individual behavior management. The descriptions offered by these experts on their current observational data coding and analysis practices closely matches findings from Hayes' work and expands upon it by translating it to a population with slightly different disabilities (specific to ID) and a somewhat older population of students. This work also incorporates recommendations made on contemporary advances technology that were unavailable at the time of their earlier work (2008).

9 Discussion

The narrative of my research has been to understand access to technology education for individuals with intellectual disabilities through the lens of 3D printing. The studies described in this dissertation tackle issues of access and accessibility from multiple directions and for multiple stakeholders. Each study has provided insights, barriers, and opportunities for each subsequent next step and many other branches of research I simply did not have the resources to follow through on. In this chapter, I will revisit my central and secondary research questions in order to construct answers drawn from the studies described above.

9.1 What Are the Barriers to 3D Printing Education for Individuals with Intellectual and Developmental Disabilities?

In order to understand the unique barriers to 3D printing education for this special population, I needed to gain insight into the context of 3D printing education and special populations. The only trouble with this statement was the sheer lack of such a context. While 3D printing had been gaining popularity in mainstream education and hobbyist spaces, it was still far from established in special education and sites where I could leverage observation and contextual inquiry were very limited.

I had to break this question down into secondary questions. To explore 3D printing in special education, I sought to understand how it was being implemented in mainstream education while I searched for opportunities to observe 3D printing in special education.

9.1.1 How is 3D printing being taught in mainstream education?

In Chapter 4, I generated a baseline understanding of 3D printing for novices, with an emphasis on youth learners and mixed styles of mainstream learning environments. Via interviews with multiple stakeholders, I gained an understanding of the best practices for teaching 3D printing to students and other novices. Among these best practices, I learned that offering rapid and early gratification helps to bolster novices confidence in their skills and their commitment to printing, providing step-by-step scaffolding can be beneficial in some contexts but tedious in others, and the common pitfalls of new 3D designers can be mitigated with supervision but must be balanced against a loss of empowerment.

I learned what hardware and software to use, the types of lessons that engaged students, and I learned about managing expectations. A host of software options existed for novices, but there was no one-size-fits all for an individual's ability level, and I found that low cost printers had shortcoming in the form of reliability, fidelity, and speed. From educators and youth designers, I learned that 3D printing can be tedious and error-ridden, but teaching students to think critically about their designs and work in small teams helps to mitigate these errors and reduces frustration. If students could be encouraged and supported over the more frustrating hurdles of 3D printing, they gained confidence and self-esteem when met with design challenges and printer troubleshooting. I also found that because 3D printers generate tangible artifacts, they can function both as a learning tool and a reward system by supplying a physical reward for skills learned and demonstrated.

Based on my field work, 3D printing was being taught as a haphazard trial-and-error, with a mix of oversight (and undersight) and a type of light-weight chaos that, I would come to find, was simply not going to stand up well in a special education environment with its additional variables. I highlighted the best parts about learning incentives, optimizing lessons for success, and avoiding pitfalls in my field notebook and carried on with my research.

9.1.2 What Are the Barriers to 3D Printing in Special Education and for Persons with Disabilities?

In Chapter 5, I was able to study the contrast of 3D printing in special education, as opposed to mainstream formal and informal learning environments. I found that many of the benefits and rewards for 3D printing translated well to special education, and it included novel benefits to students with disabilities. However, despite my learnings from mainstream education's best practices, there were still many barriers for students with intellectual and developmental disabilities learning 3D printing. While I was aware that the slow speed and lack of reliability of printers would be troubling for any user, these issues were particularly difficult for students with IDs. Broken printers caused students frustration and distraction. Slow printers contributed to poor mental models of the design-to-print process for a population of students who needed more concrete connections between the abstract and digital to the physical and tangible. Students did not always perceive the long-term gains of carefully planning a design and how this was strongly correlated with successful 3D prints.

Students in special education environments struggled with 3D-modeling software in the same way that their peers without disabilities did, but often had additional difficulties accessing interfaces and completing design tasks. Difficulty designing in three-dimensions and navigating complex and foreign software menus compounded confusion and made it difficult for students to remain on-task. In a special education classroom with only one or two teachers or teaching assistants who knew how to complete 3D modeling and design tasks, this proved to be an overwhelming environment for everyone. Despite the excitement and interest from the students and many of the other stakeholders in the school, the 3D printer became a sore point in the technology classroom and was left to languish in disuse. Free resources and free training for the educators were not enough to make this "novice-friendly" technology accessible and consistently engaging for students.

In Chapter 6, I investigated the broader issue of access to 3D printing technology. This study started as an exploration of low cost and highly specialized assistive technology as produced by 3D printers, but quickly revealed a lack of community diversity. The assistive designs themselves were only a small fraction of the designs available on the Thingiverse repository, but even within that highly specialized design sub-space, the target-users (i.e., persons with disabilities) were not the designers of these devices the majority of the time. Most of the individuals contributing to the design of 3D-printable AT were men without disabilities who had either educational or job-training in STEM fields. These individuals were making devices for friends, family, or even no one in particular. They rarely consulted people with disabilities during their design process and never followed up with target-users of their designs who were not in their immediate family. Many of the designs also included multiple and/or external parts in order to be completed and functional. In these instances, designs were not only made by people without disabilities, made without consulting individuals with disabilities, but also designed in such a way that a person with a disability might not be able to manufacture these designs without assistance.

These findings painted a bleak picture of a community that specializes in design using the contemporary poster-child technology (i.e., 3D printers) of do-it-yourself values. The technology for 3D printing clearly has its own barriers, but the composition of the Thingiverse AT design community suggests a systemic lack of access to technology and technology education for persons with disabilities. My studies exploring applications of 3D printing in special education suggested that 3D printers could be used to make tangible learning materials for individuals with sensory and learning impairments or to create bespoke AT artifacts for individuals with dexterity and motor impairments. Despite the range of applications, the largest repository of 3D models on the internet had comparatively few AT designs and the majority of AT designers did not have disabilities themselves. \

The barriers to 3D printing in special education encompass those found in mainstream education and pile on additional novel barriers. Novice designers struggles with hardware reliability, tool mastery, and designing in three-dimensional space all apply and compound for an individual with an intellectual disability and would likely translate to other individuals with limits to their cognitive function. Additional considerations are found in limits of executive function, reading comprehension, and problem-solving. The iconography style and vocabulary used in modeling tools may be difficult to interpret. The limited amount of tool-driven learning scaffolding means educators must fill the gap between laconic or highly technical tutorials and the needs of students who are dependent on UDL and 21st Century Learning. However, in trying to get a better handle on these 3D-printing-specific obstacles, I found that there were more sources of technology barriers impacting learning for students with ID.

9.1.3 How Might an Inclusive Learning Environment Mitigate Barriers to 3D Printing Education?

In Chapter 7, I presented three semesters of ethnographic action research designing and iterating on an inclusive learning environment to teach 3D printing alongside themes of entrepreneurship and social good. I attempted to mitigate technology barriers, limited teaching resources, and the delicate balance of engagement and trial-by-fire skills building of 3D printing using peer learning in an integrated, postsecondary classroom. I generated a range of assignment styles for individuals and teams to encourage students to work at their individual levels of ability. I leveraged the physical output of 3D printing as a reward system to help keep students engaged with material. And, to a certain extent, this worked.

For three semesters, I was able to teach every student in my class how to find existing 3D models, inspect them for printing, and successfully print those objects. The majority of students with moderate to low support needs could also modify or design their own 3D models from scratch and successfully print those, too. Among students without disabilities, perceptions about people with ID often changed over time. Undergraduate students without disabilities went from having little or no knowledge of intellectual disabilities to a clearer understanding of the diagnosis and a self-described change in perception about the abilities of people with IDs. Students without disabilities recognized individuals with ID as fully capable people with unique support needs and that those with IDs are more than able to learn the skills and complete the actions necessary to create 3D models or troubleshoot printer hardware.

However, the inclusive learning environment was not a silver bullet. Students still struggled to learn 3D modeling, fought with printers, and within teams, personalities and social dynamics were challenging at times. During the first semester of this course, I watched undergraduates with disabilities take control of design tasks in anxious effort to ensure that assignments were completed correctly—the underlying assumption that their partners with disabilities could not do the work or would fail to do it fast enough. A lot of factors contributed to this perception—social stigma surrounding individuals with disabilities, of course, but also an observable lack of accessibility of software and hardware for students with cognitive impairments. Despite the relative novelty of 3D printing, students with ID were still behind their peers in their base-line technology skills. Limitations in memory, recall, and planning made navigating complex software and file systems difficult.

The implications of those limitations are far-reaching. Students must be able to turn on and sign into a lab machine, navigate to the appropriate websites and online portals, sign into accounts for design tools, course management systems, and email. On any given day, a student in postsecondary education (PSE) is expected to maintained multiple sets of credentials, memorize or explore multiple dynamic and static online and local systems, search for and delineate good information from bad information on the internet, and decipher any number of unfamiliar information architectures with their iconography and naming conventions. For an individual with ID, any or all of these tasks and skills could be profoundly difficult and require a wide range of support to be completed.

I also watched undergraduates completely checkout mentally, allowing their partner to do all the work because they perceived that they themselves could master all the content on their own time and had no interest in helping or cooperating with their peers. Technology literacy strikes again! Undergraduate students felt they could count on their own technology savvy to complete assignments rapidly at the end of class or even outside of class. But their social discomfort with disability left them standoffish and uninterested in helping their peers with disabilities who struggled with abstract icons, new vocabulary, and multi-step design planning. Sharing responsibilities or communicating outside of the classroom was dismissed out of hand, with students with ID struggling to access email accounts due to issues of memory (e.g., forgetting log in details) and having a limited understanding of digital file management (e.g., whether or not a file is digitally shared and what happens to it if it is altered).

Going into the second semester of this course, I tried to mitigate these attitudes with a variety of low- and medium-fidelity interventions. I gathered personality characteristics to help make better social pairings for teams. I tried simply suggesting or telling students to make sure they were taking turns during in-class assignments. I even went so far as to install local software that would initiate a pop-up every so often to force students to take turns. Most students ignored me and my technology interventions. Over time, I found the best intervention was for me to be personally wary of who was and was not cooperating with their partner and make an extra effort myself or via a classroom assistant to be present and enforce what I perceived to be positive learning behaviors. Of course, after consulting with domain experts, I discovered my looming and interruptions were rarely, if ever, helpful.

Ultimately, inclusive education helped to address some barriers related to 3D printing, but I did not account for the complexity and the depth of accessibility barriers tied to technology itself as a presence in a classroom. Novices struggle to learn 3D printing tools because part of being a novice 3D model designer is a lack of familiarity with the symbols and the vocabulary of design in three dimensions. For a person with ID, that same lack of familiarity and steep learning curve can be echoed in nearly every technology interface or system we encounter and require at the PSE level. While I did identify benefits of inclusive learning, I also realized that there was really more to be addressed than merely making 3D printing more accessible. I believe inclusive education is an excellent way to promote learning and help dispel some of the stigma surrounding disability, but it is not a substitute for truly accessible technology and technology education.

9.1.4 What is the Role of Technology in Inclusive Education?

At this point in my studies, I knew there were barriers to 3D printing and to the other technologies that permeate higher education. I was also unsure how I could use technology to make inclusive education more successful in the context of technology learning or PSE. My sense as a teacher, was that I was seeing specific interactions and behaviors among students that were less desirable than others, but I was not able to accurately define and articulate what problems I should be looking for and preventing. It was not as simple as pairing everyone with a good social fit and reminding students to take turns. As a technologist, I also felt like there were so many opportunities to improve my classroom experience, but what I had tried so far was failing.

For my final study, Chapter 8, I took a step back and I made the determination to reflect on my findings from a special education standpoint. Having captured video data from two of my three semesters working in this ILE, I selected a subset of teams and team behaviors to discuss with special education domain experts. My timed turn-taking idea had fallen flat and so I asked the broader question, what can technology do to support inclusive learning? My domain experts had very clear answers and modest requests. Instead of focusing solely on the dynamics between teammates, my investigation needed to be more cognizant of the individual support needs for different students and how their peers' behaviors impacted those needs.

The domain experts I interviewed consistently suggested that I monitor for positive and negative behaviors for individual students first and then consider how technology can support or intervene on those behaviors second. Rather than interrupting students and forcing them to take turns every ten or fifteen minutes, I should be observing or, ideally, automating the documentation of individual student behavior and intervening intelligently. In this way technology, can stretch the existent resources in a classroom. A one-to-one ratio of teaching aides to students is not necessary if information about each student can be recorded and supplied in a timely information to one or two instructors. Additionally, my domain experts reinforced a second principle I had only loosely defined—the students whose behaviors might need adjusting are just as likely to be those students without disabilities as those with them. A passive, systemic ableism suggests that the students who need support and intervention are the students with disabilities, but in this ILE it is just as beneficial to tell a student without a disability that they need to engage more with their partner, not dominate learning activities, or be engaged themselves with content.

Further discussion from Chapter 8 identified a wealth of good applications for technology in special education environments. What is more, these requests and ideas are nearly identical to the requests and ideas from a study done 10 years ago. I discussed Hayes' work briefly in my related literature (Hayes et al., 2008). They co-designed a system called CareLog to capture the relevant behavioral information from a classroom for special education teachers. What is really stunning is that in 10 years, the need to document certain behaviors, to have control over the frequency and duration of documentation, and the needs for analysis really have not changed. Yet, technology still is not being used to capture this information. I have extended this work looking at a new environment and a different population. Specifically, I have looked at inclusive postsecondary education with young adults with intellectual disabilities. Since Hayes' work, technology has only gotten faster, smaller, and smarter.

We are just now seeing mobile devices and wearables being applied as assistive devices for students with IDs. One of the main challenges in this space is a perceived and sometimes very real inability of technology to tag behavioral data as accurately as a human. My contribution to this problem, as discussed in the next chapter, is a coding system for video data as a first step toward creating better behavioral coding in a smart or augmented learning environment. More details about this are in the subsequent chapter, but I bring this up as a clear indicator that in 10 years of advancements in technology, we are still not applying the full force of our resources to improving education access for students with disabilities.

Intellectual disability as a diagnosis and behavioral psychology as a discipline are not new, especially compared to the age of technology as a discipline. But technologists still insist on designing for the “average” user and we dismiss these fringe cases. When asked, everyone would likely agree that technology ought to be accessible, but few industry leaders put in the effort to make this happen beyond what is legally required of them. And, infuriatingly, this is just as true for education technology as it is for enterprise software or video games. People with disabilities have limited access to education and the legislation in place to assist them is incomplete. If students with disabilities had better access to technology education, they would be better equipped for the rising technology workforce and they themselves would be contributors to the future accessibility of those products and services.

This dissertation is a call to action. This document and all of my related publications have provided explicit suggestions for how we can make technology more accessible and use technology to support inclusive education. From 3D modeling and printing software to recording behavioral change in special education. I have watched students, questioned educators, and become an educator and advocate myself in the process. I think our best path forward is to leverage humans and technology to create more supportive education. By implementing more intelligent learning environments that mix integrated education practices with the tools that can more closely track and tailor materials for individual students, we could have a tremendous impact. Encouraging peer learning and the desegregation of special education, allows us to address the social challenge of limited knowledge of and experience with persons with disabilities. By exposing people without disabilities to their peers with disabilities, we help tear down those negative misconceptions about disability. Consider my last six years of field work as a long case study into all the ways we make technology inaccessible for these students and all the ways we could be building better opportunities for them.

If we make classroom technology to support inclusive learning, we support all students. We reduce burden on teachers, provide richer data on student progress, and can potentially generate more individualized learning opportunities. Educators know what behaviors to look for and they know what techniques and approaches to deliver and when to deliver them. Those behaviors and moments are detectable and trackable with technology.

10 Conclusions, Limitation, and Future Work

10.1 Conclusions and Contributions

For my small set of stakeholders, this work has had an impact on their skills, their self-efficacy, and perhaps their future career choices and opportunities. There is still a systemic lack of access and a widespread set of misconceptions about disabilities. This dissertation has not been about identifying a small problem and generating a solution for it, but rather to deeply understand a very complex problem space and arm future researchers with the knowledge and frameworks to tackle a multitude of barriers. The contributions from this work fall under two categories: (1) understanding the role of technology in education for persons with disabilities, both as a subject and a medium of learning, and (2) recommendations and best practices for 3D printing with an emphasis on improving access to 3D printing and how this technology can benefit persons with disabilities.

10.1.1 Contributions to Inclusive Technology Education and Education Technology as a Medium for Learning

As people who both create and teach technology, we have a responsibility to make our tools and learning materials accessible to all. While observing and teaching students with IDs in secondary and postsecondary settings, I found their biggest barrier to 3D printing was actually the everyday technologies they interfaced with while accessing learning content as much or more so than the 3D printing technology itself. My recommendation for educators teaching technology is to think very carefully and be selective in the software you use in your classroom and to make sure you are serving as many learning styles as possible when designing your curriculums. In my studies, I documented students with IDs struggling with complex menu hierarchies, abstract icons with little or no supporting information, vague or jargon-heavy interface text labels, memory-intensive password complexity requirements, and reductive, recall-based file systems. Features like these can sometimes offer aesthetic appeal, in the case of abstract icons or limited labelling, and sometimes expert users want or even expect a feature-dense menu system. But these software interfaces do not often support novices to 3D modeling and they create palpable obstacles for people with IDs and likely a wider circle of people with cognitive impairments.

As a technologist, do what you can to avoid these patterns and incorporate more dynamic assistance and broader consideration in your creations. As an educator, when systems with these kinds of barriers are the only valid option, leverage low-tech solutions and behavior theory to help support students who struggle. Consistency and step-by-step scaffolding are a powerful way to supplement an inaccessible interface, offering students the chance to build up positive behaviors to help them complete tasks.

What is more, we can leverage existing educational techniques like ILEs and both incorporate and augment these practices in our classrooms using technology. By introducing an integrated and inclusive learning environment, my students were able to offer each other a higher level of individualized support while learning 3D printing. This system was more successful than the independent work and instructor-led model I observed in secondary special education. While my students still struggled with interfaces and advanced design concepts, there were more resources available to them in the form of their peers and the social interactions accompanying those learning experiences were beneficial to all students.

My publications and some of the appendix material in this document offer more detailed recommendations for running an ILE. To further reduce the burden on instructors, I believe we should be working toward automating or augmenting existing special education and behavioral theory with technology. My recommendations and contributions here include my qualitative video coding scheme and the preliminary evidence of using visual cues combined with localized data, such as cursor input or software tracking, to help identify relevant behavior patterns. As we can detect and analyze more diverse pieces of data, we will be able to more closely replicate the expertise of special educators in monitoring and labeling positive behavior, again freeing up educators to focus on education rather than managing individual behavior.

10.1.2 Contributions to 3D Printing Education and Its Applications for People with Disabilities

Framing my exploration of education and technology access for persons with disabilities in the lens of 3D printing has also yielded a number of contributions specific to this technology. My early work on teaching 3D printing to novices, youth, and persons with disabilities has been among the seminal work in this space. I have generated a number of recommendations about reducing the complexity of 3D modeling interfaces, creating more supportive and dynamic tutoring and feedback systems to help with the design-to-print process, and also offered many project and curriculum ideas for educators.

More specific to persons with disabilities, I authored several papers that have since been cited in a larger body of work being carried on by multiple authors exploring the use of 3D printing as a means to create custom assistive technology and what it means to be a person with a disability and a maker. I developed an open-source tool called GripFab that was an early prototype software to help physical and occupational therapists design 3D printed therapy aids without training in 3D modeling. This work has been used to explore 3D printing curriculum in graduate level physical therapy education and has been extended by other labs to explore automated design using situational, parametric, and constraint-based 3D modeling and 3D printing.

10.2 Limitations

The studies described in this document include a few limitations that should be acknowledged. Qualitative work is not always as highly transferable as one might like. While I believe that my findings related to interface complexity and the value of peer-learning are likely applicable to other populations of learners, to prove so would require additional, targeted studies. I have tried to be clear in my language that any themes or coding schemas I have used are specific to my population of individuals with intellectual disabilities wherever appropriate. It is also worth noting that due to the highly individual needs of students with IDs and the unique classroom environment I designed, there may be additional considerations of how closely contextual details are tied to explicit findings.

Similarly, I have focused on 3D modeling and 3D printing as an emergent technology. As a discipline, 3D design has its own quirks and dissimilarities from other types of technology. While creating and building in three-dimensions may not be a pervasive technology experience, learning menus, navigating file systems, and deciphering glyphs and icons are a commonality of many technology-driven interfaces, and so I believe these findings do translate to systemic issues of technology education.

My sample sizes are also often small as a matter of necessity, both in that my work has included special and protected populations and because I chose to conduct deeper analyses of rich data. Limitations on my access to participants and the sheer amount of time and resources available to me means that this work is narrowed in scale and scope. I have opted to dive deep into case studies and I have relied heavily on the validation of themes and findings from my participants, the resonance of my work with their lived experiences, and the vetting of domain experts. Longitudinal field work and iterative, reflective ethnographic action research also strengthen the validity of the low sample size. Wherever possible, I have tried to shore up findings with additional sources of data—such as building interview protocols from field observations or using journal analysis to surface relevant themes to experts.

Lastly, I myself am not without biases. I am a technologist, an educator, and a person with my own experiences and perceptions. As my work shifted from broad to targeted ethnographic action research and I became more deeply entrenched in my investigation site and participants, I have attempted to incorporate means to reduce or, at the very least, contextualize my biases and how they impact my analysis and findings. This included video recordings to contrast against my field observations, expert review of videos and themes, and interrater coding of data wherever possible.

10.3 Future Work

Based on the two categories of contributions described above, I see two clear directions for future work related to this dissertation. The first is, of course, applying contemporary technology solutions in the classroom to help support students with disabilities. And the second category would be advancements and improvements to 3D modeling and printing tools. I have outlined a few explicit examples of future work in each domain.

10.3.1 Applying Technology in Special Education

Within special education and inclusive learning environments, I see several near and far term technology solutions that would benefit the stakeholders in these spaces.

<u>Automation of Behavioral Data Capture</u>

This is a simple, but highly requested ask I heard from every special educator I spoke with. The ability to automatically document behavioral data for later review was always the number one request. The data gathering process when a behaviorist is identifying behaviors and setting goals at the start of an individualized education plan (IEP) is a very intensive process. The approach from Hayes' CareLog is still the requested approach—augment the learning environment to capture data and give control over the frequency and tagging of that logged data to an instructor or aide. The system needs to be discrete, reasonably accurate, must capture all relevant data points and types for post-analysis, and be easily accessed and shared to appropriate, secure stakeholders. This would reduce the overhead on data capture for the educator or behaviorist, optimistically reduce errors, remove the analog-to-digital translation from paper tallies, and afford a small head start on analysis with the use of tagging.

Analysis and Distribution of Behavioral Data Capture

A step up from merely capturing data, special education and inclusive learning environments would benefit from support in the analysis and distribution of behavioral data. I am listing this separately because I believe the challenge here is more complex. A substantial amount of work must be done to make the analysis and distribution portion of an augmented special education environment trustworthy. Educators and behaviorists adored the idea of an automated system, but they were very incredulous that such a system would be accurate enough to meet their needs.

If the system could reliably detect antecedents and behaviors for an individual student, this would then unlock one or two excellent improvements. Automated analysis with some form of processing delay still would reduce burden on behaviors and educators in building IEPs and it would reduce the overall time needed to design and implement the goals for said IEPs. However, real-time analysis could provide those benefits and segue into real-time support and communication. Antecedents could be flagged before behaviors occur, allowing intervention, support, or just wary observation to an alerted educator. This could also be piped to discrete learning and AT devices for students to work on their IEP goals themselves and gain some independence from aides and educators.

Discrete Learning Support

There are a few devices, prototypes, and applications in the world intended to be used as support for persons with ID or similar types of cognitive impairment. These systems often provide schedules, check lists, or stimulation rewards as part of a larger behavior management system. I believe we can do more in terms of making these systems robust and discrete. Wearables and smartphone apps are a reasonable place to start—and a few researchers have begun tackling this. Applying affective computing and combining it with behavior scaffolding, reminder systems, and/or integrating data captured by the learning environment could all work toward detecting antecedents and behaviors and simultaneously alerting educators or aides while giving the student with ID a certain amount of independence to build their self-efficacy and self-determination. An on-body device or an off-the-shelf wearable like the Apple Watch ® could be used to identify an antecedent, like fatigue, and suggest a break before a student goes off task.

10.3.2 Improving 3D Printing Education

In so far as 3D printing is concerned, there are infinite possibilities for what future work could be done in this space. Simplifying design tools, making more intelligent and dynamic learning support systems, and building stronger, more visible communities of designers with disabilities are all excellent directions.

Simplifying Design Tools

Design tools right now lack what I personally like to call the Goldilocks option (bear with me).[4] Imagine the novice-friendly tools as belonging to the baby bear. These design tools are very simple, use bright colors and sparse interfaces, and supply a subset of functions needed to make a 3D design. While novices build up their understanding of 3D printing and practice designing in three-dimensional space, these simple tools are adequate.

Once the designer wants to transition to slightly more complex designs, the other option available to them is the papa bear's tool. These are the expert design suites with high price tags, engineering vocabulary, and an overwhelming volume of features and tools. The learning curve to successfully complete even a simple task in this workspace is incredibly steep and novice designers become frustrated, feeling stuck. The only resources are often static tutorial manuals or sequential video explanations posted by friendly strangers on the internet. Both the underwhelming and overwhelming tools give grief to novices. We lack the Goldilocks design tool, the one that is "just right" for a novice transitioning to an intermediate designer. One option is hiding more advanced features until the designer needs them, but this can be problematic for users with cognitive impairments if this is not implemented in a way that is discoverable or dynamic. Other options are

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[4] If you are unfamiliar with Goldilocks, she is an inconsiderate child from a fairytale who happens upon the home of three bears. In the absence of the homeowners, she eats their porridge, sits in their chairs, and sleeps in their beds. Throughout the process, she is quite picky and tries out each bears' possessions in turn to determine which one is, "just right". I will not spoil the ending for you.

clearer labels, more concrete icons, and more user education provided by the tool manufacturer. One more direction I will mention here is mixed reality design, where you may be able to count on people's natural inclinations for certain gestures and map them to modeling tasks. A similar, but flat approach, can be found in 3D modeling tools that emulate sculpting—still working on a 2D-surface, but using pinching and rubbing gestures to approximate working with clay. Using camera vision and projectors, I could foresee a practical mixed reality surface that allows the inclusion of existing objects to forego fussy metrics tools for precise designing and allow for more natural interactions reducing some of the learning curve and cognitive burden on users. However, support in this way may reduce access for a designer with motor or sensory disabilities, such as limited dexterity or vision impairments.

Intelligent and Dynamic Learning Systems

Something I found repeatedly in mainstream education and found beneficial in special education environments was expert oversight of new designers. Effectively, a stakeholder in the learning environment who has a moderate mastery of 3D modeling and 3D printing must look at 3D models and make a determination as to whether or not they will print correctly. The problems with this are additional time burdens for your local expert and the perpetual oversight can hinder a novice designer's ability to make connections between design choices and printed outcomes, as well as robbing them of some of their agency as a designer.

A step up that would combine very nicely with the previous recommendation of a simpler, more novice-friendly interface would be intelligent learning support. By offering interactive tutorials, embedded instruction, and automatic detection of the physical limitations of a digital model, we can create learning opportunities and support inside or on top of the design software. Intelligent tutors could be applied to three-dimensional design. The system could detect frustration or failure, like perpetually nudging a single polygon, moving the camera angle, then nudging it again, and moving the camera angle, nudging it again, and… . This behavior suggests the user is struggling to maintain a clear mental model of the geometry of their design and they could benefit from a tool that magnetizes one of their polygons or snaps items in place. A design or slicer program that not only detects areas of potential overhang, which some do, but gives a proactive explanation of what will happen and even simulates the way your model will fail while it prints to help teach the designer why overhang is important. All good learning opportunities that could be launched with a mix of cursory detection, action firing within the interface, and education theory.

Accessible Design Communities

Lastly, finding ways to bring people with disabilities into design communities and STEM-focused hobbyist spaces from a social and cultural level is equally important to making the tools and spaces accessible in themselves. This is not necessarily something we can build or design away with technology. The future of this work will require a deep understanding of design and maker communities with respect to the perceptions and presence of people with disabilities. Promote people with disabilities in design and STEM spaces. Advocate for inclusive practices, make accessibility a priority in your work. Build bridges, extend invitations, and place the burden of learning about disabilities and the concerns of people with disabilities onto yourself. Reducing stigma, creating inclusive learning environments, and building accessibility into design and engineering tools as a priority rather than an afterthought are all part of the optimistic future for this work.

11 Appendices

11.1 Mainstream Education and 3D Printing Interview Protocol

Adult Educators

Experience

- How long have you been using 3D modeling tools and printers?
- When did you start teaching 3D modeling and printing?
- What was most difficult for you to master? What was easiest? Why?
- What is your favorite model that you've created as a designer? Why?
- How long did it take you to get comfortable / familiar with 3D modeling? Printing?

Tools

- What are your preferred tools (as a designer) for modeling and printing?
    - Why are these preferred?
    - Are these tools different from the ones you would use to teach others? (Specifically youth versus adults?) If these are different, why?
- What do you think is the biggest shortcoming of modeling software for 3D printing?
    - And for printers?
- What do you think is the greatest strength of modeling software for 3D printing?
    - And for printers?

Teaching

- What age range have your students been?
- What experience level have your students started with?
- Please describe your approach for introducing novice students to 3D printing. (Demonstrations, hands-on learning, examples, jump right in, etc?)
    - Has this approach changed over time? If so, why?
- How do you handle printer safety? (e.g., Are there steps in troubleshooting or maintenance that students aren't allowed to help with?)
- How long does it take students using your approach to independently model / operate 3D printer?
- What steps do you encourage when students experience challenges? (e.g., If a print is going to fail, do you let it or is there a check in place?)
- Can you describe a time where your students taught each other, directed or undirected? (e.g., They are required to ask each other for help versus I was busy and an older student helped a younger one.)
- What are common challenges novice students encounter when learning 3D modeling? (Is modeling or printing harder?)

    - Of those, what is most difficult? Can you think of a specific example when this happened?
- What are common problems novice students encounter when learning 3D printing?
    - Of those, what is most difficult? Can you think of a specific example when this happened?
- What is easy or intuitive for students when learning 3D modeling?
    - Of those, what are students are best at? Can you think of a specific example when this happened?
- What is easy or intuitive for students when learning 3D printing?
    - Of those, what are students best at? Can you think of a specific example when this happened?
- What is your favorite thing you've seen a student create with 3D printing? (What is the most complex/unique/etc)
- What do you think students gain from learning about 3D modeling and printing?

Experienced Youth

Experience and Skills

- What are your experiences with making and technology?
- Are you techy or arty?
- How long have you been using 3D modeling tools and printers?
- How did you learn to create things with 3D printers?
    - What do you remember about that process?
- What was easy / hard?
- How long did it take?
- What is your favorite thing that you've created using 3D modeling and printing? (Most complex/unique/etc.)
    - How did you make it? Was it difficult?
    - Who did you make it for? Why?
- If I asked you to create [example], how would you do it? (e.g., Would you draw it first or go straight to design tools? Would you ask me for an example?) [Repeat this question with other examples?]

Tools

- What 3d modeling tools and printers did you learn on?
    - What was good or bad about these tools? (Or what did you like/dislike about them?)
- Have you learned how to use others tools and/or printers?
    - If so, what ones?
    - What (was good/bad) | (did you like/dislike) about those tools?
- What is the worst thing about 3D modeling tools?

    - And for printers?
- What is the best thing about 3D modeling tools?
    - And for printers?
- Are there tools or printers you haven't gotten to use, but would like to?
    - If so, which ones and why?
- If you could change anything about 3D modeling tools, what would it be and why?
- If you could change anything about 3D printers, what would it be and why?
- If you could create anything with a 3D printer, what would it be and why would you make it?
    - What's stopping you from making it right now?

Teaching

- Do you know about 3D modeling and printing than your teacher?
- Have you ever taught someone else how to use a 3D printer?
    - Whom did you teach?
    - Why did you teach them?
    - Tell me a little bit about how you taught them. (e.g., Did they already know about printers? Did you show them a design?)
- Have you ever helped someone who was stuck or having trouble with a 3D model or print?
    - Whom did you help?
    - Describe their problem. Did you solve it? How?
- Tell me how you would teach 3D printing to a friend who had never used one before. What steps would be involved? (e.g., What tools would you have them use? Would you show them how by demonstrating or ask them to do steps while you guide them?)
    - (Be sure to touch on modeling versus printing, printer troubleshooting, safety, and expectations.)
    - Are there steps you think they would struggle with? If so, which?
    - Are there steps you think they would understand right away? If so, which?
- [Repeat this question set for a younger person, like a sibling or a friend's sibling.]
- [Repeat one more time for an adult, like a parent.]

Inexperienced Youth

- Have you heard about 3D printers? Can you tell me about them?
    - When was the first time you saw a 3D printer? What did you think?
- Do you know how 3D models are made? Can you tell me about them?
- Have you used a 3D printer?
- If so, what did you make?
- What printer did you use?
- How did you make the model? / Where did you get your model from?

- If you could print anything with a 3D printer, what would it be?
    - Why would you print this?
- Would this be for you or someone else?
    - If for you/someone else, what would you print for [the opposite]?
    - Why would you print that?

11.2 3D Printing and Special Education Interview Protocol

BASIC QUESTIONS

These are just some establishing questions to help frame the discussion. Our focus is the 3D printers, but we would like to get people thinking in terms of the possibilities of 3D printers as education tools and as a path to rapidly delivered, low-cost, and customizable assistive technology. We would start off with a general description of making and do-it-yourself culture, then start asking some questions to gauge each person's knowledge of 3D printing technology.

- Have you ever used a 3D printer?
    - If not, have you seen or heard of them?
    - If yes, let's talk about how and where you used a 3D printer in the past.
- What do you know about 3D printing process? (maybe specifically what you can make with it)
    - Does your prior knowledge match the intro you just saw?
- Are you aware of any of the online communities that support people using 3D printers?
    - If yes, do you participate? How?
- Did you know there was a 3D printing facility on campus?
    - Did you ever stop by to look at the printer or ask questions? Why or why not?
    - Do you know who to talk to about it?
    - Did you ever inquire about using it? Why or why not?
- Do you know about any of the software tools involved?
- If yes, which? Have you used them?

STAKEHOLDERS & TARGETED QUESTIONS

Administrators

Exploring high-level regarding the 3D printer in the IT classroom.

- What are your expectations for the printer in the classroom?
- Are there similar programs or tools in the school? How do they compare?
- Do you have any concerns? (Liability, safety, reliability, etc.)
- How do you feel this benefits the students? The school community?

Assistive Technology Specialists

Looking at the technical side of the 3D technology and its potential for AT solutions.

- What expectations do you have for the use of 3D printers?
- Do you see uses for 3D printed objects as modifications to assistive devices? As standalone devices?
- Do you have concerns about using 3D printed objects for AT?
- Who do you see designing 3D printed AT devices?

Therapists

Looking at the applied uses of 3D technology to help with therapy or in the design of AT.

- These questions would vary by therapy type (occupational, physical, art, etc.).
- What were your plans before you got the printer?
- What expectations do you have for the use of 3D printers?
- Do you see uses for 3D printed objects in your work? Why or why not?
    - If yes, let's talk through some of those uses.
- Do you have concerns about using the 3D printer or 3D printed objects? (Customization, reliability, robustness, toxicity, etc.)
- Do you think your students would use 3D printed objects?
- Is there anything preventing you from using this technology? Technical skills, time constraints, or other issues?

Instruction & Technology Experts

Getting ground-level information on the printer itself, how it's being used, what are the benefits, challenges, and so on.

- What expectations did you have for the 3D printer?
- Did you have concerns before using the printer?
- What have been the biggest challenges in teaching the printing technology?
    - How do you maintain student engagement?
    - How do track learning/progress?
    - How do you manage expectations for the students?
    - How do you approach issues of property rights? (Thingiverse, student designs, industry sale, etc.)
- What have been the biggest challenges with the printer itself?
- How do you resolve any problems that arise with the printer?
- Have you trained anyone other than a student on how to use the printer or the software?
    - If yes, let's talk about who and how the training was done.

Non-Technology Instructors

Finding other applications for 3D printed objects within the school. Focusing on instructors who teach subjects outside the IT classroom that might benefit from tactile aids or physical representations.

- What expectations do you have for the use of 3D printers?
- Do you see uses for 3D printed objects in your work? Why or why not?

    - If yes, let's talk through some of those uses.
- Do you have concerns about using the 3D printer or 3D printed objects? (Customization, reliability, robustness, toxicity, etc.)
- Do you think your students would use 3D printed objects?
- Is there anything preventing you from using this technology? Technical skills, time constraints, or other issues?

11.3 Integrated 3D Printing Curriculum Design

Course Design

The goal for the first three class sessions was to encourage students to get to know each other and form teams. To this end, the other instructor and I paired off undergraduate students with young adults with ID based on common interests that the students mentioned during icebreaking exercises. Weekly lessons covered a brief history of 3D printing, the parts and maintenance of Printrbot Simple Metal printers, tutorials on the Tinkercad modeling software, product design, development, and marketing. Each topic was introduced for a full class period (50-minutes) followed by brief instructions and assignments in subsequent lessons. Students completed in-class tutorials, took part in discussion, and completed daily journals. In addition to daily journal entries, students completed four assignments and two projects during the semester. Journal entries provided students with an opportunity to reflect on what they learned and to work on their writing skills on a regular basis. Assignments were narrow in scope and typically focused on only developing one or two skills, but projects required students to use everything that they had learn during the semester.

Assignment 1 required students to write a short autobiographical sketch. This was an extension of the icebreaker activities and also served as a means for the instructors to evaluate each student's comfort level using a computer and cloud-based file storage.

Assignment 2 required students to compile a list of items from Thingiverse that they would like to print for themselves or for someone they knew. This allowed the students to familiarize themselves with the existing 3D models and served as an introduction to Creative Commons Licensing[5], which dictates how created works can be used. Understanding Creative Commons is both a digital literacy concept and important for the entrepreneurial portion of the course. Additionally, the designs students selected were later used in an affinity diagramming session to help students consider what types of objects might be marketable in preparation for their next assignment.

[5] http://www.creativecommons.org/

Assignment 3 required students to sketch out a product design, create the 3D model in Tinkercad, and then write an accompanying product description. This exercise targeted skills related to creativity, design, and marketing.

Assignment 4 asked students to create an invoice form that could be used to collect customer information and order details from potential clients. With this assignment, students worked on skills related to finance, customer service, and planning by taking into account production costs, client needs and specifications, and the time necessary to design and manufacture a 3D-printed product.

Project 1 required the creation of an instruction manual with explanations of how to log in to Tinkercad, use Cura to print 3D models, and how to calibrate a Printrbot. Only one set of instructions was created per group and the completion of this assignment required both communication and writing skills.

Project 2 tasked students with the creation of their own line of products that could be sold to potential customers. This project was a cumulative assignment, and it required students to use the skills that they developed throughout the semester to create three design concepts, of which they had to select two to implement as 3D models. Of the two models, one was printed and used in a class presentation to pitch their product line.

Toward the self-employment and entrepreneurial concepts in the course, the class also worked together to fulfill a request to print 100 Braille rings as a promotional material for the department. This was a time-sensitive task with a one-week deadline. To fill the order in time, students had to optimize their printing schedules and coordinate with each other to track their progress toward the total quantity requested.

11.4 Student Pairs Video Open-Coding Draft Scheme

I considered several different approaches and structures for coding my video data during my initial evaluation and attempted coding passes. This included coding schemas based on the roles of the actors, their individual and team behaviors, and environmental factors such as room layout, the technology available, and so on.

<u>Roles</u>
Team – Two students working together, one UG and one ID (e.g., T#)

Alternative Teams – Students usually have one consistent partner throughout the semester, but because of the high rate of absenteeism for both student populations, students often get paired temporarily with another team, student, or even an aide because their partner was gone that day.

UG Student – Undergraduate student without a disclosed disability (PU#)

ID Student – Young adult student with intellectual disabilities (PI#)

Co-/Teacher – Lectures, grades, designs assignments (PT#)

Aide – Monitors the classroom, floats between students and teams, offers help and guidance (PA#)

Team Behaviors

These actions are either mutually conducted and/or mutually observed between two students who are working together during that class period. Mutually conducted: students have a discussion where they talk to each other; mutually observed: one student points or gestures while the other student watches.

Talking (e.g., discussing assignment)

Gesturing (e.g., pointing at the screen)

Turn-Taking (e.g., exchange of mouse or keyboard use)

Individual Behaviors

These are behaviors or attributes of an individual that may impact or be representative of the positive or negative assessment of an interaction. These can include things an individual student does to or with their partner that have positive or negative connotations or may be behaviors that indicate a potential statement of mind or attentiveness.

Posture (e.g., open or closed posture with respect to their team mate)

Gaze (e.g., focused on their partner, on another individual, or elsewhere in the classroom)

Talking (e.g., talking to someone who is not their partner)

Utterances (e.g., sighing or frustrated noises)

Interruptions (e.g., teacher makes an announcement, someone not from the team asks a question, etc.)

Modeling (e.g., demonstrating how to do something) versus *Performing* (e.g., doing on behalf of someone else)

Gestures (specifically gestures that do not serve an actionable purpose toward accomplishing a task or communicating something, e.g. snapping hair ties or rubber bands, repeatedly rubbing one's head, spinning chair, etc.)

Environmental Factors

People (e.g., students elsewhere in the classroom make noise but are not directly engaged with the team)

Technology (e.g., computer will not turn on, program quits abruptly)

11.5 Special Education and Behavioral Experts Video Review Protocol

Course Description
This is an integrated university-level course about 3D printing and entrepreneurship. The 3D printing class teaches the basics of 3D modeling and printing using a print-shop model, where students design and sell small items made with the printers. There are an equal number of students with intellectual disabilities (ID) and undergraduate (UG) students without disclosed disabilities, and all students work in mixed ability teams of two for the duration of the semester.

The class has no prerequisites and can be taken by students from any major. This is a block class once per week lasting 2.5 hours, with a 30 – 60 minute lecture, 10-minute break, and then lab time to complete assignments or work on projects.

The students with ID are part of a postsecondary program for young adults with ID that focuses on teaching employable skills and self-determination. These students take a mix of practical classes targeted at their independent living skills and integrated electives with other students on campus.

Team Details
One female student with ID and one female undergraduate (UG) without any disclosed disabilities. The student with ID was aged 24 enrolled in the young adult program and the UG student was age 23 enrolled in a BA for business technology administration.

Second team, one female student with ID and one male undergraduate (UG) without any disclosed disabilities. The student with ID is aged 24 enrolled in the young adult program and the UG student is age 26 enrolled in a BA for business technology administration.

Third team, one male student with ID and one male undergraduate (UG) without any disclosed disabilities. The student with ID is aged 24 enrolled in the young adult program and the UG student is age 26 enrolled in a BS for information systems.

Scenario 2
The students are designing a desk decoration (such as a paper weight or pen caddy) for their clients: physical therapists working at a local medical school. Working as a team, students should create two unique designs, make drawings for each and a 3D model for each.

Scenario 5
The students are working independently on an assignment, but talking to each other about how to complete it. The assignment consists of an existing 3D model that the students are meant to recreate using their modeling tools (Tinkercad). Students are expected to use the skills they already have to guess and check how to make the right shape.

Questions

- What is your age?
- What is your current occupation? How long have you worked as X and is this where your main special education experience comes from?
- Do you have experience with integrated education? If yes, how much/long?
- Do you have experience with intellectual disability? If yes, how much/long and what age groups?
- In your experience, what are common obstacles to positive learning interactions for students with ID?
- What, if any, interventions do you use to correct negative interactions?
- What, if any, practices do you use to reinforce positive interactions?

[Summarize the course (details at top) and the team of interest for these clips (top). Then give the scenario details before each clip.]

- Clips questions [repeat for scenarios 2 and 5]
    - In your opinion, was this a positive, negative, or neutral interaction?
        - Why?/What led you to this opinion? (i.e., Were there observable behaviors or other factors that influenced your opinion?)
    - Would you intervene or reinforce any behaviors in this interaction?
        - Which ones?
        - How?
        - Why?

[After all scenarios have been discussed.]

- Are the interactions you saw in these clips typical of the interactions you have seen in your experiences?
    - Were there behaviors you were expecting to see, but didn't? What and why?
    - Were there behaviors that were unexpected? What and why?

- Do you think any of these interactions are specific to working with computers as opposed to other modalities?
- Would you suggest any changes to the way this class is taught? (e.g., What is your opinion of using mixed ability pairs? Should each student have their own computer? Are there distractors in the environment?)
- You mentioned [list interventions and supports the participant has described], are there existing technologies that would help you implement interventions or supports like this? [Give an example if the question is unclear.]
  - Can you think of an intervention or support that you would like to see implemented as a technology? [Give an example if unclear.]
  - [Below are some examples if the clips do not create any discussion. These are based on my field work and teaching experience.]
    - Receiving a notification if a student is off-task.
    - Automatically counting fidgeting or other monitored habits.
    - Replace physical counter clickers with wearables.
    - Warn a student when they are doing X.

12 Glossary

3D Modeling and Printing Pipeline and Terms

This section provides an overview of the 3D-model-to-print process and a brief glossary of terms used throughout the paper. An object begins as a 3D model generated with a CAD or 3D scanning tool and is exported as an .STL (stereolithography) file. To prepare the .STL for printing, the file is processed in a slicing program. The slicer translates the model into a printer-friendly set of instructions for layering the plastic. The final file is transferred to the printer through external storage (SD card), wired (USB), or wireless (WiFI / Bluetooth) connection and the design is printed.

Printer Hardware

A basic FDM printer, such as a Printrbot Simple Metal[6], feeds plastic filament through a heating element and then pushes the melted plastic in fine ropes through an extruder nozzle onto a print bed. As the layers increase in vertical height, a 3D object is created.

- Filament (Figure 2.1): Printer filament comes spooled and is available in two types, ABS (acrylonitrile butadiene styrene) and PLA (polylactic acid). ABS is most similar to the plastic found in LEGO® bricks, while PLA is a derivative of natural starches. Both filaments can produce robust prints in a variety of colors.

- Extruder (Figure 2.2): The extruder heats filament to its melting temperature. Most ABS and PLA plastics melt between 180 ° and 230°C. The thickness of the extruded filament is determined by settings in the slicer software.

- Print bed (Figure 2.3): The resting surface for extruded plastic is called the print bed. To help with filament adhesion during the print process, the bed can be coated with tape, gripping material, or water-soluble glue. Depending on filament type, the print bed may be heated to assist with adhesion and reduce warping as the plastic cools.

[6] http://printrbot.com/shop/assembled-simple-metal/.

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