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Bootstrapping: The Emergent Technological Practices of Post-secondary Students with Mathematics Learning Disabilities

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Abstract

Drawn from an investigation of the emergent technological practices of post-secondary students with mathematics learning disabilities, this case study employs an enactivist framework in considering the bootstrapping processes our participants report engaging in when using personal electronic devices for academic support. Video-recorded, semi-structured interviews were conducted with nine post-secondary participants with mathematics learning disabilities in two western Canadian urban centres. Findings suggest that participants used technology to control and improve sensory input in order to better access mathematics course content and monitor the accuracy of their work, engage with alternate presentations of mathematical concepts to enhance their level of understanding, reduce workload, and improve organization. We discuss how their strategies in using technology relate to Bereiter's categorization of bootstrapping resources (1985), including imitation, chance by selection, learning support systems, and piggybacking. Grounded in a "learner's perspective," this case study identifies technological adaptations and strategies that may be helpful to others with mathematics learning disabilities.

The purpose of this article is to characterize the ways in which post-secondary students with mathematics learning disabilities (MLD) learn to use and adapt their use of personal electronic devices to support their learning needs. Almost all post-secondary students are able to access technologies for their academic studies (Galanek, Gierdowski, & Brooks, 2018) and most use mobile devices (Chmiliar & Anton, 2018).

An increasing number of students with learning disabilities (LDs) attend post-secondary institutions (Cortelia & Horowitz, 2014), and their patterns of using mobile technology are the same as their peers who do not have LDs (Chmiliar & Anton, 2018). As well, there is a growing interest in how mobile technology can be used for education (Ally & Prieto-Blázquez, 2014; Kukulska-Hulme, Sharples, Milrad, Sanchez, & Vavoula, 2009). In a recent review of the literature, Crompton and Burke (2015) called for more research about its use in higher education, informal contexts (e.g., at home), and in learning and teaching mathematics.

Our research seeks to investigate the emerging practices of post-secondary students with MLD in adapting personal electronic devices to better suit their learning needs, addressing the following research questions: Which technologies on personal electronic devices do students with MLD use fluently and how do they learn to use them? As self-described confident users of technology, our participants were potentially “early adopters and instigators of change through their influence among their peers and through their networks” (Kukulska-Hulme et al., 2011). Our investigation of their technological practices may help to “open up” learning for others with learning disabilities by introducing new ways to use and adapt personal electronic devices. Through the analysis of our participants’ practices, this article adds to the literature in inclusive and technology education by describing ways in which students with MLD engage with technology to support their academic studies. Finally, our work highlights the nature of the trial-and-error process that post-secondary students with MLD engage in as they cobble together effective ways to support their learning and become “more able.”

Literature Review

Mathematics Learning Disabilities

Despite recent calls for a Canadian standard (D’Intino, 2017; Gyenes & Siegel, 2014), the definition of *learning disabilities* (LDs) still varies across different research, political, and clinical situations, as well as between provinces and territories (Burton, 2018; D’Intino, 2017). Some provinces, such as Newfoundland and Labrador and Manitoba, focus on at-risk students in general and are flexible in their support models. New Brunswick and Nova Scotia use a Response to Intervention model, systematically screening all of their students for learning difficulties. Other provinces, such as Saskatchewan and Alberta, use an Intelligence-Achievement Discrepancy Model, which looks for a wide disparity between the students’ level of intelligence and what they are able to achieve before intervening with a diagnosis and support, and have developed provincial documents that specifically address supports for students with LD (D’Intino, 2017). While all provinces require that some form of individualized educational plans (IEPs) be developed and put into place, some provinces require students to be formally diagnosed with LD by a psychologist or physician (e.g., British Columbia) while others do not (e.g., Quebec).

In this article, we follow the definition recently re-endorsed by the Learning Disabilities Association of Canada (2017):

Learning disabilities result from impairments in one or more processes related to perceiving, thinking, remembering or learning. These include, but are not limited to:

language processing; phonological processing; visual spatial processing; processing speed; memory and attention; and executive functions (e.g., planning and decision-making).

LDs in mathematics are complex and involve a combination of issues in brain processes including working memory, language processing, and visual and spatial awareness (Furlong, McLoughlin, McGilloway, Geary, & Butterworth, 2015; Willcut et al., 2013) that do not affect global intelligence. Researchers have noted that disabilities in reading and mathematics often co-occur in affected individuals because they share these common neuropsychological weaknesses (Willcut et al., 2013). Keeping in mind Lewis and Fisher's (2016) call for the definition of MLD to be better operationalized in the literature, we distinguish between those students who were born with brain-based LDs that affect mathematical performance (which will be our focus) and those students whose difficulties result from factors such as social or affective influences, conditions affecting behaviour (e.g., attention-deficit disorder), and medical conditions that affect global intelligence (e.g., Down syndrome).

LDs and Post-secondary Students

According to a recent report about LDs conducted by the Government of Canada (Bizier, Till, & Nicholls, 2014), 2% of the population aged 15–24 have an LD,¹ and among adults with LDs aged 15 and older who were currently or recently in school, 98% reported that their LD had a direct impact on their experiences in school. A report published by the National Educational Association of Disabled Students (Burton, 2018) noted that there has been a large increase in the rate of enrolment of students with LDs, chronic medical conditions, mental health issues, and autism spectrum disorder, while the rates for students with visual and hearing impairments and physical disabilities have remained constant (Burton, 2018, p. 18). Students with LDs² make up 24.7% of the Canadian post-secondary student population who identify as having a disability (Furrie, 2017), but they are under-represented in science, technology, engineering, and mathematics (STEM) programs (Burton, 2018, p. 10).

It can be challenging for any student to transition to post-secondary studies, but for those who have LDs these challenges have a greater level of complexity (Kreider Bendixen, & Lutz, 2015). For example, while over half of students with an LD aged 15 and over require educational support (Bizier et al., 2014), campus supports “are not typically provided in a coordinated fashion” (Kreider et al., 2018, p. 2) as they may have been in earlier levels of education. Students need to seek out supports on their own, but unfortunately, many may be reluctant to do so (Alexandrin, Schreiber, & Henry, 2008; Burton, 2018). In the National Longitudinal Study (SRI International, 2011), conducted in the United States, of young adults with LDs who were enrolled in a post-secondary

¹ We note that the overall rate of reporting of LDs is likely low. Not all countries, and not all regions in Canada, have adequate screenings to determine if children have LDs. As well, because of the possible stigma (Parette & Scherer, 2004) associated with having an LD, people may feel a reluctance to be tested, or have their child tested, and risk being officially labelled.

² This survey defines *learning disability* broadly and includes post-secondary students who report having attention-deficit/hyperactivity disorder (ADHD) and attention-deficit disorder (ADD; Furrie, 2017, p. 13).

institution, only 24% considered themselves to have a disability and informed their school. Of the rest, 64% did not consider themselves to have a disability, and thus did not inform their school, while 7% who did consider themselves to have a disability still did not inform their school (Cortelia & Horowitz, 2014). It is thus no surprise that while 94% of young adults with LDs received academic accommodations in high school, only 17% received these kind of supports in their post-secondary studies (Cortelia & Horowitz, 2014), a significant decrease. This may be part of the reason why only 38% of adults with LDs in the United States complete their bachelor's degrees (Cortelia & Horowitz, 2014). The situation in Canada is much the same: Only 35.6% of Canadians with LDs, aged 15 to 64, report having completed their post-secondary qualifications (Bizier et al., 2014).

College students with LDs who demonstrate strong help-seeking behaviours in supporting their academic needs have been found to perform as well in their studies as the general population does (Trainin & Swanson, 2005). The most common supports used by Canadians aged 15 and older with a learning disability are extended times for tests (40.8%) and teacher aids or tutors (32.7%; Bizier et al., 2014). Unfortunately, 44% of those who require technology-based support (e.g., an audio book) and 74.5 % of those who need at least one kind of specialized learning disability-specific aid or device (e.g., computer with voice recognition) do not receive it. Cost has been cited as the primary reason (71.6%) for this lack of access. Given that students with LDs are largely managing their learning needs on their own, it is important to investigate what technological practices might be helpful for them (Burgstahler, 2003).

Technology and LDs

In schools, assistive technology may be employed to assist students with MLD. In Canada, legislation related to assistive technology is a provincial responsibility, and thus definitions vary across the country (Courtad & Bouck, 2013). For the purposes of this article, we define assistive technology as “any item, piece of equipment, or product system, whether acquired commercially off the shelf, modified, or customized, that is used to increase, maintain, or improve the functional capabilities of a child with a disability” (Individuals with Disabilities Education Act, 2004, Section 300.5), providing “tools a user might rely on indefinitely (e.g., an augmentative communication device, a calculator, or text/screen reader)” (Ayres, Shepley, Douglas, Shelpley, & Lane, 2016). Although assistive technology is available in schools, it is not necessarily well used in promoting inclusion in the classroom (Abbott, Brown, Evett, Standen, & Wright, 2011) and there is a lack of research identifying best practices regarding mathematics instruction and technology (Hasselbring, Lott, & Zydney, 2006). Where technology is employed for students with LDs, it tends to be assimilated into traditional classroom practices (Olive & Makar, 2010) focused on working with text but using computer screens rather than paper (Kaput, 1992; Meyer & Rose, 2005). Thus, students with LDs may find themselves facing the same kind of difficulties as they would in using a regular textbook.

More students than ever before have grown up with regular access to electronic technology, and through this frequent exposure, many have become fluent and confident in its use (Trouche & Drijvers, 2010) including those with LDs (Garcia, 2013). It is natural for students with LDs to want to use the same mobile technology as their peers do

(Edyburn, 2013). As Ayres et al. (2016) noted, “No one standing in the middle of a store or on the street looks out of place staring at the screen of a smartphone, thus illustrating the social acceptability and validity of the technology” (p. 133). It appears that post-secondary students with LDs are active users of technology, with the same patterns of mobile technology usage as their peers (Chmiliar & Anton, 2018). In a survey commissioned by PopCap (*Survey: “Disabled gamers” comprise 20% of casual video games audience*, 2008), a multi-platform provider of casual games, 20% of its users identified themselves as being “disabled”; and of these, 11% described themselves as having a learning disability.

Mainstream technology itself is increasingly designed to offer its users flexibility. Customization enables users to adapt the navigation facilities and the way the content is presented (Treiblmaier, Madlberger, Knotzer, & Pollach, 2004) in order to suit user preferences. They can choose from menu that allows them to activate or deactivate certain functionalities (Frias-Martinez, Chen, & Liu, 2009). For those with disabilities, this kind of flexibility may be helpful. For example, Kelly et al. (2009) concluded that being able to customize an adaptable Web framework provided users with more individualized accessibility. Mainstream technology has also been adding features that would have once only been found in traditional assistive technology, such as the “read aloud” and “dictate” features now included in Microsoft Word word-processing software. Users can choose functionalities that enable them develop routines of using the technology that may go beyond what the designers may have originally intended. For instance, the developers of the video game *The Last Door* reported that 12% of the first 150,000 gameplays had the closed captioning activated, while 14% used a font specially designed for dyslexics (“Survey: ‘Disabled gamers’,” 2008). The introduction of assistive features to mainstream technologies has helped users to avoid the issues associated with older forms of traditional assistive technology such as the amount of training time required to learn to use it, cost, and portability (Ochola, Stachowiak, Achrazoglou, & Bills, 2013).

Our work responds to a need for more research to determine how effective new assistive technologies are in supporting academic difficulties (Bryant, Bryant, & Ok, 2014). There are multiple technological platforms available for student use, and in this study we have focused on the personal electronic devices that students use in their personal lives and increasingly in their educational ones. We consider personal electronic devices to include cell phones (including smartphones), personal digital assistants, iPods, tablet devices, and laptop computers. To help to highlight the characteristics of how our participants use technology, we further distinguish between types of devices and software according to the original purpose of their design as follows: “traditional assistive technology,” which has been specifically designed for the use of the disabled (e.g., Kurzweil 3000); “specialized technology,” which has been specifically designed for use in a certain subject area (e.g., Desmos for mathematics); and “mainstream technology” which has been designed for everyday use by the general public (e.g., Microsoft Word). It has been noted that mainstream devices, with their inherent accessibility features and ability to run apps designed to enhance accessibility, are beginning to supplant the use of specialized assistive technology (Burton, 2018) and in doing so they have “changed the way persons with disabilities interact with the world around them” (Burton, 2018, p. 19).

Bootstrapping: Learning to Use Technology

Our research is informed by the theoretical framework of enactivism as it applies to the relationship between students and technology (Li, Clark, & Winchester, 2010). A theory with a postmodern perspective (Coles, 2015) and roots in radical biology (Maturana & Varela, 1987), Buddhism, (Varela, Thompson, & Rosch, 1991), phenomenology (Merleau-Ponty, 1962), and the second wave of cybernetics (Bateson, 2002), enactivism conceives of cognition as an active process: For the purposes of this article, we note five “highly intertwined” central ideas of enactivism that have been identified by Di Paolo, Rohde, and De Jaegher (2010): autonomy, sense-making, embodiment, emergence, and experience (p. 37). Organisms are autonomous in that they not only react to the current conditions of their environment, but they regulate their reactions and are able to set up new ways of acting. Thus, their sense-making is not just a matter of gathering information from their environment, but of generating meaning and being transformed through this process—they “enact a world” (Di Paolo et al., 2010, p. 39). As organisms interact with the environment, the environment in turn is influenced, which in turn affects the organisms and so forth, a process of co-adaptation referred to as structural coupling (Maturana & Varela, 1987). Through this interaction, emergence occurs. For the enactivist, the Cartesian division between mind and body is non-existent: “the body is ... a whole animate system with many autonomous layers of self-constitutions, self-coordination, and self-organization and varying degrees of openness to the world that creates its sense-making activity” (Di Paolo et al., 2010, p. 42). Through the body, “cognitive structures emerge from the recurrent sensorimotor patterns that enable action to be perceptually guided” (Varela et al., 1991, p. 173). As Merleau-Ponty (1962) wrote, “I am not in front of my body. I am in it or rather *I am it*” (p. 150; emphasis added).

Working from the premise that the systems of body, mind, and environment are entangled with one another (Merleau-Ponty, 1962), the theory of enactivism suggests that learning emerges through the interactions between these systems: “Cognition is effective action” (Maturana & Varela, 1987, p. 29). This points to a potential reciprocal relationship between the use of technology and cognition in the act of learning (Li et al., 2010). Enactivism has been described as an “essential tool” (Abrahamson, Flood, Miele, & Siu, 2019) for reimagining the design of inclusive mathematics learning environments as well as theorizing how learning can occur. Rather than viewing technology as a prosthetic device for the disabled, compensating for whatever it is about their minds or bodies that is deemed to be lacking (Ayres et al., 2016), from an enactivist perspective, technology moves from being an external “add-on” to the disabled body to something that becomes embodied within the learning system in its potential to open up and extend the learner’s bodily senses to new experiences and capabilities (Söffner, 2017). In this way, technology can support learning. In recent years, researchers have been investigating the relationships between technology and students with disabilities (e.g., visual impairment; see Abrahamson et al., 2019; Healy, Jahn, & Frant, 2010) and our study builds on this literature through descriptions of how students with LDs may use and adapt technology. With the increased affordances of new media which “can talk, push, and show back” (Sinclair & de Freitas, 2014, p. 363), students and teachers alike are all

learning systems becoming more “able” in one way or another through the use of technology, no matter which “abilities” they started with.

One way to characterize this process of becoming more able is through the concept of bootstrapping. Based on the idiom, “to pull yourself up by your own bootstraps,” the term *bootstrapping* refers to improving your knowledge and/or performance through your own efforts and resources. It involves a process of interaction which Jörg (2009) has identified as “generative learning,” and characterizes as “complex, self-reinforcing” with “effects which make learning unexpectedly efficient over time” (p. 7). Generative learning “creates new entities, previously unknown, starting from entities already known” (Singer, 2009, p. 59). Bereiter (1985) identified potential resources for this kind of learning, including the following:

- Imitation. This might involve observing a peer’s success in using a particular type of software and trying it for oneself: The student might not fully understand the capabilities of the software, but witnessing the peer’s performance provides a rough guide he can use as he figures out what to do. Others have suggested that imitation might also be akin to “following a recipe” (Watson & Mason, 2005). For instance, student might look up a mathematical procedure on the website Wolfram Alpha (<https://www.wolframalpha.com>) and use it as a model for solving an assigned problem. However, Bereiter (1985) noted that the imitation of models is not foolproof. “The behaviour of models necessarily contains much that is irrelevant or idiosyncratic, so that the learner needs some basis for identifying what is significant and for extracting what is invariant across modeled instances” (p. 211).
- Chance plus selection or doing “the right thing for the wrong reason” (p. 208). For instance, one might inadvertently send an email message to oneself and then realize that this would be a convenient way of issuing self-reminders.
- Learning support systems, such as apps of mathematical games. These can “focus the learner’s attention on significant variables and ... provide simplified formats for the complex interactions that are eventually to be learned and internalized” (p. 212). They provide structures intended to help their users improve their performance.
- “Piggybacking,” or “adapting already-existing systems to new uses” (p. 209). For example, technology is often designed to offer its users flexibility.

Bereiter (1985) identified some conditions that promote the act of bootstrapping. When people do not use up their “mental capacity... on the task at hand they tend to do something else with what is left” (p. 213). For example, if someone is comfortable enough in doing a task that it no longer takes up all of their mental energies, they may move to a meta-procedural level, developing more sophisticated ways to perform the task such as refining and streamlining the procedure, or exploring alternate goals that might also be achieved through performing the same task. In terms of technology, the user’s comfort might derive from being familiar with a particular device or piece of software, or from the device or software having been designed in an “intuitive” way that makes it easier for the user to work with it.

We believe that research should honour students' lived experiences (Burton, 2018, p. 2) by considering how individuals use and adapt technology on their own (Straub, 2009), not just how they have been taught to use it. In interviewing post-secondary language learners, Kukulska-Hulme and de los Arcos (2011) found that "learners are using whatever mobile device they happen to own, and when they hit upon something that works for them, they stay with it" (p. 76), something we believe also to be true of learners with MLD. Thus, our study is situated within emerging research on the "learner's perspective" on the use of technology (Kukulska-Hulme et al., 2011) in the context of increasing learner autonomy, personal choice of devices, and ways to use those devices.

Methods

This qualitative research is an in-depth exploration of a central phenomenon (Creswell, 2012; Guest, Bunce, & Johnson, 2006), allowing us to hypothesize about relationships between students and technology that might otherwise remain unconsidered (Yin, 2014). The excerpts we discuss in this case study were drawn from an exploratory research project investigating the emergent uses of personal electronic devices by students with MLD from two post-secondary institutions in western Canada.

Recruitment and Selection of Participants

We used purposeful sampling to recruit participants who currently attended post-secondary institutions in two cities in western Canada and who self-identified as having a learning disability that affected their performance of mathematics. Further in our sampling, we sought volunteers who identified as being confident in using technology, as these students were more likely to be regular and enthusiastic users of personal electronic devices who were willing to discuss and demonstrate their practices. We believed that participants with these characteristics would be "information rich" (Patton, 1990, p. 169) and thus able to provide us with valuable insights into how mobility technology might be better used to support learning (Demouy, Jones, Kan, Kukulska-Hulme, & Eardley, 2016). This proved to be a challenging population to access. Students with LDs may be reluctant to disclose their disabilities due to societal stigmas (Parette & Scherer, 2004). As well, they have a high cognitive load in terms of navigating the demands of their academic schedules, and simply may not have the time to spare to participate in a research study. We actively recruited participants for a period of seven months (early autumn to early spring) through both campuses' accessibility centres (i.e., counselling staff distributing flyers), as well as through posters in the student centres, postings on campus electronic listservs, and presentations to student groups. In the end, we conducted video-recorded, semi-structured interviews with nine participants ranging in age from late teens to early 40s who were enrolled as on-campus students in academic programs including computer science, business, science, and social sciences. By the final interview, our data was sufficiently saturated in terms of common practices and strategies. Given the small number of participants, and following research ethics guidelines to preserve participant anonymity, we are using pseudonyms and offering descriptions of participants that are necessarily general.

Development of Interview Questions and Protocols

Our methods align with our theoretical framework in that we used a strengths-based approach in working with our participants that allowed for maximum participation and accessibility (Alper & Goggin, 2017) during the interview process. We conducted semi-structured interviews, using an interview protocol that was developed and refined during the previous summer through a pilot study with two other participants. The interviews featured open-ended questions about how students used their devices and their opinions about them (Swan, van't Hooft, Kratcoski, & Unger, 2005), and these questions were emailed to participants a few days ahead of the interview to give them time to think about the topic. Students with LDs sometimes struggle with language processing, which may include verbal expression, so we employed an interview style that privileged doing, demonstrating, and gesturing as well as speaking. Participants were asked to bring their own personal electronic devices to the interviews so that they would be able to show us the technology they most frequently and comfortably used. Our interviews included questions meant to prompt participant reflection about the technology they used, how they used it, and how they learned to use it, such as: What technologies, applications, and strategies have you used in the past? Would you show me how you use your current technology and applications for support? How does it help you? Are there ways that you use or customize your technology that may be different from the ways you think other people would do it? How did you figure out what to do and how to do it? During the interview, we encouraged participants to build on their previous answers if subsequent questions triggered new ideas. All of this helped to prompt participant narratives about their experiences with their MLD and their use of personal electronic devices, encourage participants to demonstrate their uses of technology, and promote a more “natural” conversational style within the interview discussion, which may have helped our participants to feel more at ease.

Data Analysis

As this was an exploratory study of post-secondary students’ technological practices, we used grounded theory (Glaser, 1978) to identify emergent themes about the characteristics of our participants’ uses and adaptations of technology. According to enactivist theory, as it is difficult for observers, including researchers, to move beyond their own perceptions, it is important that multiple sources of data are used and that different perspectives are part of the analysis (Reid, 1996). As enactivist researcher Alf Coles wrote,

The methodological principles in this article will not guarantee that two different researchers going through the same process will end up making the same distinctions. The aim, rather, is that different researchers would end up agreeing about distinctions and would learn, themselves, through the process, while being able to say something about distinctions made within the transcript. (2015, p. 245)

Our process involved recursive analysis of the video recordings, interview transcripts, field notes from research assistants about their impressions immediately after conducting the interviews, and our own research notes, followed by a search for patterns (Coles, 2015). The first stage involved independent open coding (Corbin &

Strauss, 1990) that was grounded in the participants' own words (Li, 2013) by the each of the two main investigators to help foreground different interpretations (Li, 2013) and initial themes. This was followed by a comparison of these interpretations to help us notice emergent features about our participants' technological practices (Demouy et al., 2016; Kukulska-Hulme & de los Arcos, 2011). As we were interested in characterizing how participants with MLD learn to use technology to support their studies, we then returned to the literature with the dominant emergent theme of "trial and error" in mind. In this article, we use our data to further develop the ideas of Bereiter (1985) about bootstrapping.

Results

In this section, we report on our participants' accounts of how they use technology to support their learning, focusing on what devices and software they use, how they learned to use them, why they use them, and how they use them, offering excerpts from the interviews as descriptive evidence of some of their practices. Our participants all had MLD, and some had also been diagnosed with additional disabilities, including dyslexia, non-specified reading disabilities, issues with working memory, attention-deficit/hyperactivity disorder (ADHD), attention-deficit disorder (ADD), and obsessive-compulsive disorder (OCD). No two had the same combination of diagnoses. Our analysis revealed that the overarching theme characterizing their behaviour was "try and see" or "trial and error," a process of cobbling together ideas from a variety of sources, seeking out and trying new things, and keeping what was most effective. As one of our participants, Suzanne, remarked, "It has been trial and error for my whole life. These are the things that I have adapted, that have worked the best for me that I still use today."

What Did They Use?

All of our study participants reported using mainstream technology in their everyday lives as well as at school, including devices (e.g., laptops, tablets, and cellphones from a variety of companies including Apple, Dell, Samsung), software (e.g., Microsoft Office, Adobe), search engines (e.g., Google, YouTube), websites (e.g., Khan Academy, Wolfram Alpha), and apps (e.g., Photomath, which enables users to take a photo of a mathematics question and receive a step-by-step solution; www.photomath.net). Two participants mentioned using specialized technology (e.g., GraphPad Prism [scientific graphing and statistics software], www.graphpad.com; Desmos [online scientific graphing calculator], www.desmos.com) that had been specifically required for some courses in their academic programs. Three students used traditional assistive technology, which included smartpens (various companies; this device records what is said during the lecture and what the user writes and links these recordings to notes taken in an interactive notebook) and text narrators (e.g., Kurzweil 3000, Natural Reader).

How Did They Find Out about Technology and Learn to Use It?

Participants came to use their technology through a combination of what happened to be available (i.e., devices their families and schools had on hand; the software that was

already bundled on these devices), what they were taught to use, what others around them were using, and what they discovered when searching for further options.

Formal instruction in how to use technology to support learning was infrequent. Participants who had been diagnosed with LDs early in their education or who had been not yet been diagnosed but received extra support anyway, received one-on-one or small-group support from their student services (special education) teachers in elementary school through pull-out classes, as well as some in-class support from their classroom teacher through adapted assignments (e.g., fewer questions, more time to complete them, opportunities to work in quiet locations outside the classroom with fewer distractions) but were not taught how to use traditional assistive technology. These students recalled practising low-tech “study skills” (e.g., how to highlight the important words in a book using a brightly coloured felt pen) and receiving extra attention from the teacher. The exception was Lauren, who was offered technological interventions to assist her with reading: She participated in the Fast ForWord program (a reading recovery program) and was taught how to use Kurzweil 3000 software to have her texts electronically narrated.

In terms of formal learning about electronic technology, Paula was the only participant to recall taking a general “computer class” in elementary school. There she and her classmates learned basics about using desktop computers, information that she draws upon to this day. In their post-secondary programs, Paula, Evelyn, and Fiona had been trained to use specialized software (e.g., Desmos, Excel, GraphPad Prism) for specific courses. Once they were familiar with the affordances of this kind of software, they tended to still use it—with the exception of GraphPad Prism, which has expensive licensing costs.

All participants had received advice, or informal direct instruction, about using technology, and this came from a variety of sources.

I just went to [the on-campus computer store]... The lady who runs it just kind of gave me a quick little “This is how you do it.” And then the Accommodation Center also gave me a quick “How to do it.” And then they kind of just said, “Go home, play with it, and see what you can do.” YouTube videos, I watched a lot of YouTube videos. The call-support guys, I probably called them six times while I was trying to figure it out. They are great. They help out a lot. But yeah, it’s just a learn-by-yourself kind of thing. (Lauren)

In most cases, participants continued to use the software they already knew. They appreciated when new software interfaces were similar to what they had already been using (or that were, as one participant described it, “intuitive”) so that they did not feel like they were having to “relearn it over again.” The Microsoft Office bundle was a popular option because it came pre-loaded on devices and was familiar to participants. Some participants mentioned receiving some help from family members to learn about the assistive features of mainstream technology.

With my computer, I have the setting on there that if you highlight the text, you press, I think it is command-exit, it speaks what you’ve highlighted. I have an uncle, he is very good at technology, he told me that one. And I also have a setting on there where you could speak to the computer and it writes it out in text. My uncle also showed me that one. That one I would not have figured out without him. I am thankful for him.... My older brother is very good at technologies and phones, and so I learned how to change the size of the text

when he was showing my dad, because my dad can't read the text that's small. And I can just sit in the back, and be like, "Hmmm, that will be helpful for me, too." So that I pick up a lot of stuff just from eavesdropping on other people's conversations about technologies. (Lynn)

Participants also actively searched online for ways to improve their use of their technology. They considered what they needed and then "searched it up" online to find out information about available options, including how to download or order a product. Marcel, for instance, had been looking for a text narrator that was better than the text-speech feature included in the Microsoft Word software that he had been using initially. Through a Google search, he found and downloaded the assistive technology Natural Reader (www.naturalreaders.com).

While doing research about LDs for a course assignment, Lauren had discovered and then joined a Facebook group about LDs whose members regularly exchanged information about resources and strategies.

[Members] all post different websites and articles, and things like that. I really enjoy that because I can just go back and see what they have to say.... So what I did was I just kind of searched "learning disability group"... On this [there is] a whole bunch of parents, teachers, and students, and so they all tell their stories. They all upload articles and stuff. They've all helped me so much. It's just like a little family. (Lauren)

Finally, sometimes it was more of a happy accident: Participants might have been using a device or app for one purpose and then realized that it would also work for something else. Dana described how she first discovered videos as sources of information about mathematics when she was on Google looking for websites, and some YouTube videos were also listed. Once she watched a video, she noticed more were recommended, "and then I was hooked."

In the end, participants were aware that finding what worked best for them was a process of trial and error. As Fiona explained, "I'll keep what I have and try the other thing. If that works better then I'll switch over, but I would have to make sure, I wouldn't just drop something unless I knew the other thing I'd tried [was better]."

Why Did They Use Technology?

In general, our participants used technology to make their academic lives easier. It helped them access, capture, and process course content; it assisted them in finding additional information about the mathematics content that made more sense to them; it reduced their workload in terms of decreasing the time and effort required to read assigned texts and check the accuracy of their work; and it helped them practise basic arithmetic skills.

I think that [technology is] not so much for learning, it's more an assistance with it. I don't think it's actually teaching me anything, but it's making it possible for me to do this stuff. Otherwise I wouldn't be able to. You know, more like a crutch but not with [the] negative [connotation]. I think crutch sounds so negative; people are like, "You're just using it." It's that you need it to walk, so how is that negative? So, it's not teaching me anything but it is supporting me so I can keep moving forward. (Fiona)

Accessing and capturing course content. Our participants' main use of technology was to access mathematics content information both during and outside of class. Participants made use of resources posted online by the instructor, including lecture notes, PowerPoint slides, and assignment sheets; but they noted that their instructors did not always make these resources available. During class, some participants audio-recorded the lecture, which enabled them to focus on what the instructor was writing on the board and saying rather than scrambling to take notes. Afterward they could then listen to the recording to reinforce what they had experienced during class and take notes at their own pace. Most participants tended to rely on the audio-recording features on their phones, but three students used (or were about to start using) a smartpen, which enabled them to take some notes that were linked to an audio-recording of the lecture that was made at the same time.

Although students noted the importance of what the instructor was writing on the board during class, none of the students reported video-recording their instructors' lectures or having access to video-recordings supplied by their instructors. Some participants used their phones to take photos of what the instructor had written on the whiteboard or was displaying on the screen with an LCD projector, although they reported that this was sometimes tricky to do so before the instructor erased the board or moved to the next slide, and impossible to do if they were currently audio-recording the lecture with their phone.

With math it's a little harder, the lectures are more ... they're writing on the board and I can't videotape the class so I don't always see where it's at so I do find that [the audio-recording is] not as helpful as it is with other classes.... The math class you would pretty much need it to be [video] recorded so you can see what he's writing at the same time. If you're following [him] you tend to have the completed equation and you don't know what point he is [on] with the board talking about stuff because you need to physically see the writing. And then in the Math 110 classes [the instructor] kind of thinks you have a basic understanding that I don't. So, he'll skip some simplifications steps so he'll get one line—and I'll be fine—[and go] to the next line, [and] he'll have skipped a couple of steps that he thinks everyone should know and I'm just like "How did that just happen?" Wave the magic wand and now there's a number on the bottom. That's what it feels like. (Fiona)

Those participants with language processing issues mentioned using electronic text narrators to help them with their course readings. Listening to the electronic narrator while following the highlighted text improved their ability to access the text's meaning and maintain their focus, and it also reduced the amount of energy they needed to expend to complete the reading. One participant described how the text narrator helped her with word problems, a notoriously challenging aspect of school mathematics,

because it's so difficult for me to read something when there are two separate tasks that are needed. So that I need to read something and pull out the problem in it. It can be very difficult. So, having the technology of a computer to read it back to me can just take away one of those problems for me, so that I can focus more on the numbers or what I need. (Lauren)

Lauren further noted how electronic access to texts had improved over the years. The campus accessibility centre was able to get her electronic versions of most, if not all, of her textbooks, and the articles assigned in class were usually distributed electronically as PDF

or Word files, which were easily uploaded into Kurzweil 3000. She noted that although she had an electronic scanning device to use for texts, she rarely needed it anymore.

Supplementing course content. Sometimes students wanted information about alternate procedures that were different from what their instructors had offered, in hopes of finding an alternate method that made more sense to them, perhaps illustrated with visuals or real-life examples.

I also always look up videos, just in case the way the teachers did it isn't kind of working for me. Sometimes [the video] doesn't explain things and I just don't know. So then I go over to things like Khan Academy where sometimes they can teach me more of the basics of a more complicated question, or just another way of doing it, or visualizing it, [which] can suddenly make things kind of sort of click, so you get it.... Sometimes the Khan Academy only actually has one way to do the equation and stuff. So sometimes then I also look at YouTube. Sometimes, YouTube will have, like, other ways of doing the questions. (Jackie)

Students also searched for information about the concepts underlying the instructor's procedure—ones they were certain that they had been taught before but could no longer remember or did not understand in the first place. However, finding appropriate videos could be complicated: They often did not entirely match the course content, and it took time to find videos that explained the concepts using a variety of methods. Participants viewed online resources critically though, for example, comparing various videos with one another and also with viewer comments to check the accuracy of the content.

Usually you can compare what you are doing to other YouTubers too. So, you can figure out if somebody is doing something wrong [laughs]. And then you can go to the comments and see somebody say, "Oh no, you did it wrong. That's not how it's supposed to be." So usually, that's what happens. (Dana)

Improving accuracy of mathematical calculations. People have been using standard handheld calculators for decades to improve the accuracy of their arithmetic, but for those with LDs there can be an extra challenge in using them.

[Demonstrating a calculator]: I've lost my visual on [a standard calculator] after I've hit equal here and here.... [But with Google calculator] after I've hit equal [button] I still have that [display that shows what I've input] there so I can look and make sure that I've tapped in my numbers correctly. Because that's something else I sometimes do, reverse my numbers or I'll miss zeroes. Zeroes are the worst. When you've got a thousand, how many zeroes is that? And they all look the same, so there's nothing breaking it up. My mind kind of jumbles over that. Here I can physically put my paper up [beside the screen] and make sure that I've typed in all those numbers correctly. It just gives me that extra reassurance that I've done it correctly, but also that ability to see what's happened.... Google is my go-to guy [laughs]. (Fiona)

Guided practice. Sometimes students sought further background information about the procedure their instructor had used in class, or simply more details about the procedure itself, particularly if the instructor had skipped steps when demonstrating the solutions. Participants used technology to find further information about these mathematical procedures, including websites that offered fully worked-out solutions for textbook assignments (e.g., clegg.com, slaters.com). Participants frequently mentioned

using specialized websites, such as Khan Academy, that featured a menu of videos, quizzes, games, and other resources from which they could pick and choose, according to what they needed.

Basically, I usually just research or search in it what I want to learn about, and then it plays videos, and then... questions from the videos, and then it has like, okay, you don't get the concept, and it will go "View this video based on this concept."... And then you answer the questions; the questions usually have videos linked to them. So that if you don't quite get it, or need to review it, you can watch the video again. And then if you still don't get it, it will actually show you how to work it out. (Jackie)

For more informal practice, a few participants mentioned having used mathematics game apps in their spare time to build and review arithmetic skills.

Reducing workload. Because of their brain processing issues, the academic workloads for students with MLD are more demanding than they are for other students. As a result, these students often take fewer post-secondary courses per term because they require additional time to complete the work. Even then, anything that helps to reduce time spent on doing readings or completing assignments is much appreciated. As mentioned, text narrators helped to reduce the time and effort participants spent on the process of reading, so that they had more energy left to focus on the content. Similarly, software programs like Excel and GraphPad Prism offered automated formulas, which helped to reduce memory load as well as the potential for inaccurate input, meaning students could focus instead on data trends and their meaning.

[Demonstrating GraphPad Prism]: This is calculating the standard deviation so you just type in "stdv" and then the entire thing. It tells me right here how off something ... like, you can see there's a very small error bar—It means the data points are very close together. That's a high point so this one has a fair range, but there's no way I could have created a chart like this without this program. I can't calculate standard deviation. Even with the formula I get mixed up, I get confused, and here, all – I just have to type in "stdv" and what numbers I need to do and it's done. Yeah. So, this has got all my equations.... This is actually a full change in growth. There's no way I could calculate that without this program. (Fiona)

How Did They Use It?

Participants used technology to control the quality of the sensory input they were receiving from what they were reading, viewing, or listening to, modifying it to make it more accessible and easier to interpret. Of her frequent use of text-to-speech and speech-to-text features, Lynn said, "I am pretty the only one [in my classes] that talks to my computer, and then has their computer talk to them." Some students had developed routines for setting up documents to make them more accessible. For instance, students changed the default setting of Microsoft Word and PowerPoint documents to increase the font size and to switch the font type, although each student had different preferences as to what was most effective for them (e.g., one participant preferred Times Roman for improved readability, while another student specifically avoided using it). An interesting method of improving readability was through the adaptation of the low-tech practice of using coloured filters. Two participants had received recommendations from

psychologists to use a transparent coloured plastic Duo-Tang cover as a filter by physically laying it over the pages they were trying to read in order to make the text more readable. The participants then each tried achieving this same effect for electronic documents. Lynn said that, at first, she tried physically laying the plastic cover over her laptop screen but found this was awkward. Then it occurred to her that rather than using the Duo-Tang cover as a filter, she could work with the electronic document itself, and change its background colour to green to achieve the same type of contrast with the text. Lynn had actually sold her roommate, who did not have a learning disability, on the idea of using a coloured background. Another participant, Lauren, had come up with a similar method, although her background colour of choice was orange, and she was now hoping to find programs that would automate the process.

In using videos, participants also reported controlling their sensory input:

So I guess when I am watching those videos to help myself outside of class, I always have a pen and paper, but [the size of the video window is] always maximized, so it's like I'm in the classroom watching, and then I will pause it, too. Lots of time, I don't know if you notice this, but I will be writing something, but the teacher is talking so fast, I am focusing on writing and not on what is he saying. So at least with these videos, I can like pause it, write my own examples, write my own words out, zoom in to what's he's saying.... [I]nstead of only getting 50% of the lecture, I am getting 100% of what I'm watching. I am doing more work with my time. I'm learning more, because I'm actively understanding it and going at my own pace instead of just showing up physically, but mentally I am not there. (Suzanne)

Discussion

As the brain issues involved in MLD are varied, affecting working memory, language processing, and visual and spatial awareness (Furlong et al., 2015; Willcut et al., 2013), students with MLD require a wide range of supports in order to assist them with performing calculations, accessing mathematical texts, following lectures, and so on. All of our participants used technology to support their academic needs, relying mostly on the mainstream technology with which they had grown up (Garcia, 2013; Trouche & Drijvers, 2010). Our results show how our participants were able to take advantages of some of the affordances of technology to extend their bodily senses to new capabilities (Söffner, 2017) to support their learning. Participants improved their ability to see and read texts by using technology to focus their field of view (through zooming in and by highlighting relevant words) and to make text more readable by changing its style and size and by increasing the contrast between text and background. They were able to transform text-to-speech through electronic narrators and, potentially, through speech-to-text, although few of our participants reported using this. They were able to capture aural information in class, whether by recording with their phone or through a smartpen, and to hear and process it better by pausing the recording, repeating it, or changing its speed.

Given the independent nature of post-secondary studies in comparison to earlier levels of schooling, it is not surprising that all of our participants felt that they were largely on their own in terms of finding ways to support their learning needs, regardless of when they had been first diagnosed or their level of contact with the campus accessibility centre. Almost all described their method of learning about the possible

affordances of technology as “try and see” or “trial and error,” which mainly involved exploring different ways to use their current devices and software, going online to find new ways to support themselves, and keeping those that worked (Kukulska-Hulme & de los Arcos, 2011). Our results indicate that through this trial and error, which we connect with the concept of bootstrapping, all of our participants reported being able to reach a level at which they felt they were able to support their MLD adequately through the use of technology. In the following section, we discuss evidence of our participants’ bootstrapping behaviour in relation to the categories identified by Bereiter (1985).

Bootstrapping

Bootstrapping involves working with current resources and pushing for “better”—tweaking what you already have, seeking new information and possibilities, experimenting, keeping what works, and improving what does not.

Imitation. This is perhaps the most common pedagogical strategy employed in the North American educational system—the teacher models, the students follow. One-on-one interactions with a teacher or tutor have been a popular way of supporting students with LDs: The student can ask questions and request alternate explanations; their work is closely monitored; feedback is prompt and specifically directed; and subsequent tasks are just a bit harder. However, a post-secondary lecture hall situation where an instructor is modelling for a large class and rarely interacting with individual students can be challenging for those with LDs. Our participants used technology to capture the content of these lectures through audio recordings (cellphone and smartpen) and photos (cellphones) giving them time to process the information and imitate the procedures later and at their own pace. Finally, they reported keeping their eyes and ears open to what their peers and family members were doing with technology to be alert to what else they might try.

As Bereiter noted, modelling itself has limitations (1985), and we see this as a spur to further bootstrapping. Our participants described how their mathematics instructors might not review underlying concepts, perform all steps, or explain concepts or procedures thoroughly enough. Our students bootstrapped their understanding by using websites that offered fully worked-out solutions to textbook questions and seeking other sources of information, a process that ranged from simply typing a mathematics question into Google, to finding websites and videos that offered more information about a specific mathematical topic. Our participants bootstrapped their experience of watching videos by searching for and viewing other videos on the same topic, by reading comments from other viewers to see if anyone had corrected the content or challenged the solutions, and by continuing to search for “better” websites and videos.

Learning support. This resource offers the user a series of lessons, activities and/or questions meant to support them in moving to higher levels of performance. Our participants did not mention any experiences with computer-assisted learning technology or mathematics tutorial software, although a few reported using on-line games in their spare time to practise arithmetic skills. Several participants mentioned Khan Academy which, with its videos, quizzes and games, could be considered to be less tightly structured form of learning support. One participant bootstrapped her use of Khan Academy by referring to other online sources of mathematics videos, at the same time

keeping them available on multiple open browser tabs so she could more easily move back and forth between them.

Chance and selection. The happy accident made while working on something could be quite subtle, possibly something that was hardly noticed; and work might continue with little memory of the mistake that led to a new practice. It may be for this reason that only a couple of our participants mentioned this type of resource (e.g., Dana’s inadvertent discovery of mathematics videos on YouTube mentioned earlier).

Piggybacking. All our participants piggybacked on what might be considered to be baseline-level uses of technology in order to improve accessibility. For example, the average student may sometimes glance at the display of an online calculator to check his input, but likely only if the answer to the calculation is unexpected or if he knows he had difficulties entering the numbers (e.g., he was distracted or tired). In contrast, a student like Fiona knows that she needs support to ensure she has typed in the numbers correctly, so she makes an effort to change from using a standard handheld calculator to using an online version that displays her input. Most participants transferred their use of low-tech practices—such as highlighting important passages in a text to enhance readability—toward developing corresponding high-tech practices (Kaput, 1992; Meyer & Rose, 2005) and certainly mainstream software is designed with features that facilitate this (Treiblmaier et al., 2004). However, participants also described routines they followed in setting up a text before they would begin reading it. For instance, Lauren’s and Lynn’s use of coloured backgrounds shows them moving beyond the “normal” aesthetic use of this feature in order to use it to improve their reading experience. That Lynn’s roommate, who did not have any LDs, also took up the same practice brings to mind the Universal Design for Learning philosophy that if a practice benefits someone who is disabled, it will likely also benefit someone who is not.³

Participants also took advantage of the media player controls for videos, using them more frequently and intentionally than a general viewer might in order to get as much out of the video viewing and listening experience as possible. Many of our participants also reported that they often searched online for “how to” learn more about their technology in order to use it more effectively. For example, Marcel reported that he first started using the built-in text narrator of Microsoft Word on the recommendation of the staff at the campus computer store. Finding the narrator’s voice too stilted, he began searching online for a better option, which led him to upload and try Natural Reader. Although this app was an improvement, he said he was still seeking a less “monotone,” more natural-sounding, reader voice, and he was currently searching for videos of real people reading the text or discussing a particular topic.

In summary, bootstrapping their use of technology helped our participants to learn mathematics. It has allowed them to access mathematical texts more easily as well as to access the information being delivered by their instructors more effectively. It has enabled them to review materials at their own pace. It has helped them to see and hear alternate presentations of mathematical concepts and to find some answers to their questions. Finally, it has allowed them to check their accuracy and to automatically plug

³ One of our research assistants also ended up purchasing a smartpen for personal use.

in formulas, so they could focus on the mathematics itself—patterns and meaning—rather than on the logistics of performing repetitive calculations.

In considering our participants' practices, we noticed that as they became comfortable using a technology, they had also "become more able" by either developing more effective ways of using it or by using it for "new" purposes. As well, they seemed to have become more aware of other possibilities, and asked themselves what else they could do with current technology, or what other technologies were available that might allow them to do a particular task "better." Their goals in doing all of this were modest. As Suzanne noted, "With all the resources in place it's manageable, you know. I am not going to be a brainiac in statistics, but I'm able to pass the course, which is what I need to graduate."

Limitations

Although this article describes what some students with MLD report about how they use and adapt technologies to support their studies, this is an exploratory study with a small sample, and so these findings cannot be generalized. As well, it is difficult to capture real-life practice; our data is based on what participants are aware of doing and are willing to self-report, so it is not a record of all of their practices. We hope our findings provide some indication of which strategies participants found to be effective. As technology continues to evolve and become more prevalent in school classrooms, user practices will evolve, making further research about this topic worthwhile.

Recommendations for Practice

Evidence-based understandings of students' technological experiences and insights are essential to improve student access and equity. Based on our findings, we recommend that post-secondary mathematics instructors make use of technological resources to help their students bootstrap themselves along, such as posting videos of their lectures online and recommending other mathematics videos that describe alternate approaches. They might also consider changes to their teaching style, for instance, considering the style of the "flipped" classroom, in which students are asked to view lecture videos on their own time and to spend class time working on and discussing mathematics problems together. Finally, while there have been recent developments in teaching mathematical concepts through technology, only two of our participants mentioned the use of specialized technology (Desmos and GraphPad Prism) for graphing and statistical analysis. Having students explore the affordances of dynamic software that lets students "do" mathematics through movement (e.g., using a mouse to click and drag the vertex of an on-screen triangle to new positions in order to explore different types of triangles) may help all students, not just those with MLD, build a deeper understanding of mathematical concepts.

Conclusion

“In an age when ‘communities are jumping across technologies’ as needs and trends evolve” (Wenger, 2010), educators, researchers, and learners themselves need to stay informed about how learners might use personal technologies as members of communities that are social, work-related, or educational (Kukulska-Hulme et al., 2011). Whatever we can do to help spread the knowledge of best practices will be of benefit to all.

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