# A Descriptive Study Examining the Impact of Digital Writing Environments on Communication and Mathematical Reasoning for Students with Learning Disabilities

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Proficiency in mathematics, including mathematical reasoning skills, requires students to communicate their mathematical thinking. Mathematical reasoning involves making sense of mathematical concepts in a logical way to form conclusions or judgments, and is often underdeveloped in students with learning disabilities. Technology-based environments have become a strategy to enhance students' reasoning in mathematics. Unfortunately, little research investigates the effects of technology on the reasoning skills of students with learning disabilities. This study examines the effects of an intervention intended to promote the communication of mathematical thinking through a digital writing environment for students with learning disabilities. We examined how students used the digital writing environment, the information communicated, and differences in mathematical reasoning for a small group of elementary students with learning disabilities ($N$ = 13). Findings revealed students communicated primarily mathematical knowledge, preferred typing most of the time, and engaged in mathematical conversations with peers. Furthermore, significant differences in mathematical reasoning occurred over time.

**Keywords:** *learning disability, mathematics, technology, writing, mathematical reasoning*

A strong and ongoing emphasis exists on developing a population that can use mathematics effectively in everyday life (Diezmann, Lowrie, & Kozak, 2007). To achieve this goal, educators' and policymakers' focus on targeting and educating those who have difficulty with essential mathematics (Jitendra et al., 2005). Recent reports demonstrate that the mathematics performance of elementary and secondary students in the U.S. falls short in comparison to other countries, which suggests that the U.S. may not be adequately preparing students with the levels of mathematics knowledge necessary to enter a competitive 21st century workplace (Hanushek, Peterson, & Woessmann, 2010). In 2013, 14% of fourth grade students without disabilities scored below basic level for mathematical performance and this number is even less promising for students with disabilities as reports show that approximately 45% of fourth grade students with disabilities scored below basic (National Assessment of Educational Progress [NAEP], 2013).

Students with learning disabilities face numerous challenges when presented with difficult mathematical concepts and require support in order to navigate through curriculum and master content. Many of the typical charactertistics associated with learning disabilities, including weak abstract reasoning skills, directly impact mathematical understanding and problem solving (Steele & Steele, 2003). These students implement problem solving strategies used by much younger students (Geary, Hoard, Nugent, & Byrd-Craven, 2007), plateau in their math achievement at grade 5 or 6 (Cawley, Baker-Kroczynski, & Urban, 1992), and struggle to make normative gains over time. Some researchers have shown that math learning disabilities are persistent across age (Swanson & Jerman, 2006), with students remaining in the lowest quartile of mathematics achievement over the length of their school careers (Shaley, Manor, & Gross-Tsur, 2005).

Reasoning involves the ability to solve problems; however, the capacity to solve a problem is not always indicative of reasoning (Fischler & Firschein, 1987). Reasoning in mathematics requires an individual to possess the ability to formulate and represent a given mathematics problem as well as explain and justify the solution or argument to a mathematics problem and plays a very important role in mathematics (Kilpatrick, Swafford, & Findell, 2001; Martin & Kasmer, 2010). Unfortunately, students with learning disabilities often experience difficulty in this area (Bressette, 2010). Given that The Common Core State Standards (CCSS; National Governors Association et al., 2010), which have been adopted by 45 states as of fall 2012, provide eight standards of mathematical practice that emphasize mathematical problem solving and reasoning across all grade levels, it is critical that students with learning disabilities become proficient in their ability to reason in mathematics.

Reasoning and communicating go hand in hand, and some argue that reasoning improves through communication (Steele, 2007). Gould (2008) states, "learning to communicate mathematical reasoning is fundamental to understanding mathematics" (p. 2) and subsequently influences the perception of students' conceptual understanding of mathematical ideas. Therefore, becoming proficient in mathematics involves the ability to communicate mathematical thinking or engaging in an active process of constructing new knowledge (Baxter, Woodward, & Olson, 2005; National Council of Teachers of Mathematics [NCTM], 2000). Communication moves students beyond rote memorization of facts towards a conceptual level of reasoning. However, this becomes problematic when students do not or cannot communicate their mathematical reasoning.

Engaging in written and spoken communication about mathematics offers students an opportunity to explain and evaluate their thinking, which can further enhance understanding as a reflective process (Steele, 2007). In addition, the engagement process can support mathematical reasoning and problem solving as well as help students recognize the characteristics of effective communication (Pugalee, 2005; Steele, 2007). According to Cooper (2012), "…writing is a natural way to provide students opportunities to express their reasoning and expand their understanding beyond calculations" (p. 80); thus, writing has become a widely accepted approach towards addressing communication in mathematics. Connolly (1989) claims that writing develops thought processes—such as the ability to define, classify, or summarize—which are useful for engaging in mathematics. King (1982) reported that when students are stuck on a problem and write out their thought processes, they see their errors and often solve the problem. Writing also allows pictorial representations that may benefit students who otherwise struggle to find the correct language to express their mathematical ideas (Baxter et al., 2005). In a small study conducted by Baxter et al. (2005), students with learning disabilities demonstrated improvement in reasoning skills through writing in mathematics. Participants used journals on a weekly basis to record and explain thoughts related to mathematical concepts. Over the course of the study, students were able to show gains in their reasoning skills from preobservations to post-observations. Although there are many ways to support communication in mathematics, the use of technology has become a heavily implemented strategy in the classroom (Cooper, 2012; Zemelman, Daniels, & Hyde, 2012).

Currently, technology serves as a prominent tool to help educators enhance and meet the educational needs of all children by functioning as a powerful method used to promote critical, analytic, and higher order thinking skills, provide drill and practice opportunities, and engage students in real-world problem solving (Cemal Nat, Walker, Bacon, Dastbaz, & Flynn, 2011; Noeth & Volkov, 2004; U.S. Department of Education, 2010a). The advent of universal design renders technology increasingly accessible for all types of learners (Center for Applied Special Technology [CAST], 2012). Zemelman et al. (2012) identified the use of technology, such as blogs, chats, or forums, as authentic writing environments that can facilitate communication about mathematics; however, limited research has been conducted specifically on facilitating communication in mathematics through technology-based environments. Gadanidis, Hughes, and Cordy (2011) examined the impacts of a multimodal communication tools in a digital environment for a sample of gifted students. This included access to an online discussion, drawing tool, rich text, and graphics to allow the opportunity to communicate mathematical ideas in various formats. Results indicate that students chose to use the drawing feature as well as a combination of drawing and writing more often than the other tools to express and communicate ideas. In addition, they report that students had more success solving algebraic equations, graphing, and plotting. Although this study offers insight about the potential technology has for increasing communication, relatively no empirical evidence exists on the effects of communication and writing in mathematics through a technology-based environment on the mathematical reasoning skills of students, and in particular students with learning disabilities.

The purpose of the present study was to examine the effects of an intervention designed to promote communication in mathematics through use of a digital writing environment. Our research was guided by three primary research questions: (1) What type of information do students record when given access to a digital writing environment?, (2) In what ways do students facilitate communication in the digital writing environment?, and (3) How does use of a digital writing environment impact the mathematical reasoning of students with learning disabilities?

## Methods

### Participants

Participants included elementary students from two private schools in Dallas, TX (see School Overview for more details) who were in the third and fourth grade ($N$ = 13). Just over half of the participants were male (53.8%), and slightly more than three-fourths of the sample was Caucasian (76.9%), 15.4% was African American and 7.7% was Asian. Slightly less than three-fourths of the sample (69.2%) had a primary eligibility category of learning disability, while the remaining 30.8% had a secondary eligibility category of learning disabilities. Across both primary and secondary eligibility categories, 31% qualified under reading, 23% in math, 23% in writing, and 15% were general learning disabilities. Only one participant qualified for free/reduced lunch, and all of the students received instruction in English. Because our settings consisted of private schools that may or may not serve students with learning differences, the federal definition for learning disability was provided to the teachers to ensure that students primary or secondary eligibility of learning disabilities aligned. Prior to entering the private school setting, students had been identified as eligible for services under the federal definition of learning disabilities. All data reported on the checklist were teacher report via a file review of each student.

### Setting

**School overview**. The study took place in two private schools located in a large urban area of Texas. One school serves students in grades 2–12 with learning disabilities or differences. The other school serves students in Pre-kindergarten through fifth grade. Participants worked through the intervention in a computer lab for 45 minutes twice a week outside of their regularly scheduled mathematics course.

**Online learning environment.** The Math Learning Companion (MLC) program is an online instructional program designed as a supplemental mathematics curriculum for students with learning disabilities or difficulties in the later elementary and early secondary grades. It consists of 73 lessons across seven modules: Math Foundations 1, 2, and 3; Number Sense; Algebra; Geometry; and Data Analysis. Students progress through each assigned lesson by completing the following lesson components: (1) Real World (instructional set), (2) Vocabulary (introduction of new mathematical terms), (3) Instruction (explicitly delivered), (4) Try It (guided practice), (5) Game (independent practice), and (6) Quiz (10-items randomly selected that align with lesson content). The curriculum framework for MLC is based on *HELPMath©*, which shows statistically significant effects on an ELL population (Tran, 2005), and in 2012, this study met the What Works Clearinghouse evidence standards without reservations. For the purpose of this study, the teachers assigned their class a curriculum sequence of eight lessons based on what the students were learning in the classroom. All third graders completed the same lessons from Math Foundations 1 and fourth graders completed a combination of lessons from Math Foundations 1 and 2.

### Measures

**Academic variables.** Academic variables included participants' oral reading and math fact fluency as well as participants' mathematical knowledge and working memory. Oral reading fluency was assessed using the DIBELS-DORF (Good & Kaminski, 2002), which has demonstrated adequate reliability with test-retest reliability scores ranging from .92–.97. Participants read three grade-level passages timed at one minute and the median score of correct words per minute represents their oral reading. Students were also presented with a paper and pencil math fact fluency task, which consisted of completing three probes (Fox, Howell, Morehead, & Zucker, 1993): addition, subtraction, and multiplication facts, and were timed for two minutes each. Correct digits per minute for the addition, subtraction, multiplication, and division timings in mathematics were calculated and recorded for analysis. Mathematical knowledge was assessed using a curriculum aligned grade-level test that assessed their understanding of the mathematical concepts presented in the MLC program before and after the intervention.

**Math reasoning inventory**. The Math Reasoning Inventory (MRI) (Burns, 2012) is an online formative assessment primarily designed to serve as a tool for assessing mathematical reasoning by conducting face-to-face interviews focusing on core numerical reasoning strategies and understanding. Students respond to questions by explaining their thought processes while the interviewer records both the students' accuracy and strategies they used to solve problems. For the purpose of this study, only the Whole Numbers portion of the MRI was used. This consisted of 10 items in which participants were provided a problem, asked to answer the problem without the use of pencil and paper, then asked, "How did you figure this out?" During this entire process, researchers recorded verbatim what participants were saying in the notes section of the MRI. These responses were used for further analysis of participants' reasoning skills. The reliability of the Whole Numbers test includes a Cronbach's alpha of .81 and the individual questions have Point-Biserial correlation coefficients ranging from .38 -.53 (Bernbaum-Wilmot, 2012). All interventionists watched instructional videos on administering the MRI, followed by practice sessions of delivering and scoring the MRI prior to administering it in the study.

**Use of digital writing environment.** Participant behavior consisted of the frequency of use of the digital writing tools within MLC as well as minutes engaged in the online mathematics program. Daily downloads of students' "click" behavior provided frequency data from the online mathematics program. Each time a participant clicked on the notepad or the wall, that behavior was recorded and downloaded. In conjunction with the click data, the number of participant notes and wall posts were also tabulated to give both a frequency of times the participant opened each tool and a frequency of actual notes/posts made. Finally, posts were qualitatively coded across seven different variables (origin, method of entry, content type, math related information, correctness of mathematical information, socially related information, and comments).

## Procedures

Three researchers were trained by the principal investigator (PI). A structured training session was conducted and included an overview of the study's purpose, an introduction to the measures, detailed instructions on working with participants, opportunity to practice administering measures, and using the intervention script. Following training, data collectors were tested by the PI on key data collection protocol and adherence to the intervention script. Subjects participated in an intervention focused on writing in mathematics using a digital writing environment. For the purpose of this study, "digital writing environment" refers to specific tools within the MLC program; a notepad and peer-mediated wall. Participants were engaged in MLC twice weekly for 45 minutes outside of the normal mathematics time, completing a total of 8 lessons. These lessons were assigned by the grade-level teacher and participants completed them in the same order. Teachers were given information about the content of each lesson in order to make an informed decision as to which lessons were most appropriate for the participants.

Prior to completing the lessons, participants were trained on the use of writing in mathematics through the use of digital writing tools (e.g., notepad and peer-mediated "wall" or blogging tool) embedded in MLC. Researchers provided participants a scripted training on use of the curriculum embedded digital notepad including a word-processing and drawing feature, use of a peer-mediated wall (similar to blogging), and a note-taking strategy. This included a discussion on communicating mathematical thinking in the form of recording vocabulary that might be important and/or working through problems. The eight lessons were separated into four "levels" containing two lessons each. New demands were placed on participants every two lessons of the intervention. Different demands included: Level One—taking notes in the digital notepad, Level Two—posting comments to the peer-mediated wall, Level Three—responding to the questions or comments of peers, and Level Four—using a note-taking strategy. Figure 1 provides additional details of the intervention levels. All new demands were presented to participants in a scripted format by the researchers. Participants were then given time to practice on the tool before using it within their new lessons.

## Data Analysis

Several steps were implemented to analyze data and identify patterns or responses across participant groups. First, data were entered, cleaned, and descriptive statistics were generated to provide an overview of the sample. Means and standard deviations were computed for each of the continuous variables assessed. Frequencies were calculated for each of the discrete variables assessed. Finally, specific statistical analyses were conducted to address each research question. A paired-sample $t$-test was conducted to determine the gains over the course of the program on the MLC pre- and posttest.

Qualitative analysis was used to evaluate participants' notepad and wall post entries. Prior to analyses, researchers examined participant notepads and wall posts for content and created several preliminary categories as potential categories. Researchers collapsed categories after several discussions and generated a coding dictionary. The following categories were agreed upon for the notepads (a) origin—where the original note was recorded; (b) method of entry—type, write, use of symbol, or combination; (c) type of content information (mathematical knowledge/fact-based information; mathematical reasoning—attempts at solving or working through problems; mathematical questioning—questions related to math problems; mathematical answering—answers math related questions), and (d) correctness of mathematical information. The following three categories were added for the wall posts: (a) content type—social, math, mixture; (b) type of social information—directive, process statement, or questions, request for clarification, practice, or social behavior; and (c) comments—relates or does relate to post, answers a question, other. Next, researchers coded 10% of notepad and wall entries to establish reliability prior to

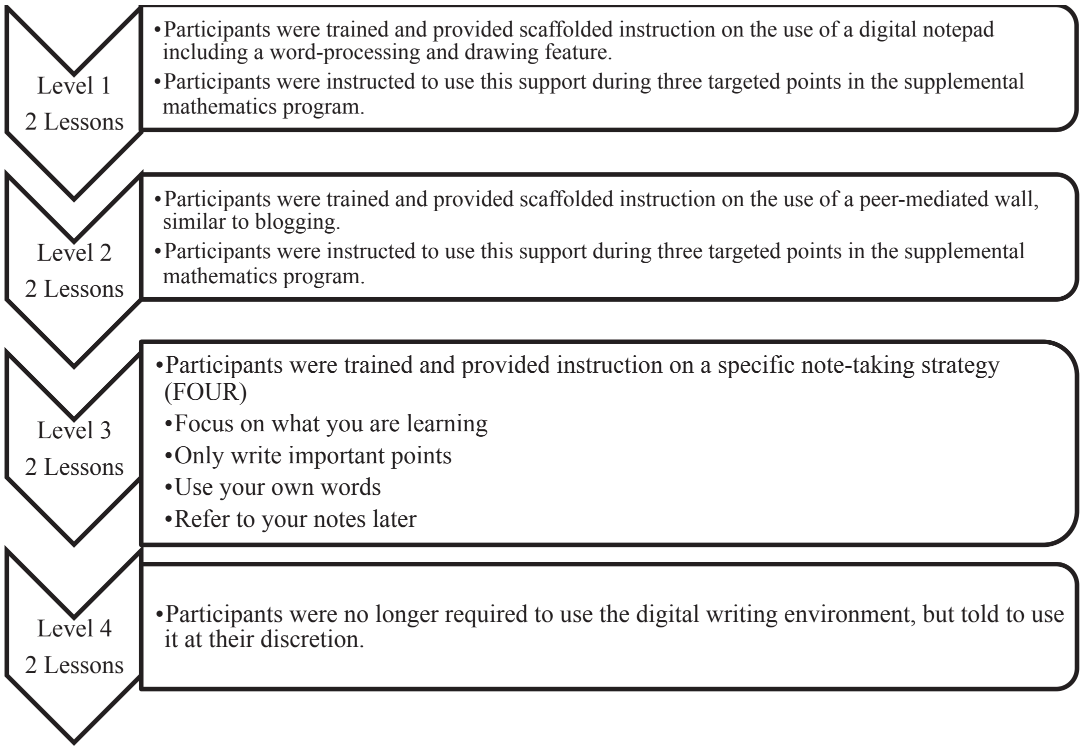


***Figure 1.*** Intervention Levels for Writing in Mathematics

coding independently reaching a 97.6% agreement across categories. All disagreements were discussed prior to independent coding.

Prior to analysis of the MRI, researchers implemented three distinct steps to code participant data. Initially, a coding dictionary was developed for each of the three components of the MRI (student answer, student explanation, and student reasoning). *Student answer* consisted of the correctness of the answer and fell into four categories: correct, incorrect, self-corrected, or did not answer. *Student explanation* measured how participants solved the problem and fell into four broad categories: used the standard algorithm, used another method specific to the problem, gave other reasonable explanation, or guessed. *Student reasoning* entailed seven categories: no attempt at reasoning, guess attempt but incorrect answer, guess attempt and correct answer, partial attempt but had a reasoning breakdown, complete reasoning with a calculation error, complete reasoning and correct answer, or entirely wrong process. See Figure 2 for examples of participant responses for each MRI category.

Next, two researchers completed reliability on 11% of the sample with an average of 95.8% reliability, and discussed all disagreements until they reached a consensus. Finally, researchers independently coded the remaining MRI interviews.  If the participant did not answer the question under the first category, the remaining categories were not coded. Therefore, a maximum of 130 responses could have been coded for this sample. Once the data were coded into these categories, Chi-squares tests were performed on the MRI pre- and posttest to determine differences in reasoning related to *student answer* (i.e., correctness of problems), *student explanation (*i.e., type of explanation) and *student reasoning*. Cramer's (Phi) effect sizes were computed to determine the magnitude of difference between groups.

## Results

### Academic Variables and MLC-Related Behavior

Table 1 reports descriptive statistics for all academic and MLC-related variables. Participants did not show a significant improvement from MLC pretest to posttest ($t_{(12)}$ = -1.761, NS). Despite not having a statistically significant difference, students gained an average of 2.23 points over the course of the intervention. On average, students used the notepad almost three times as frequently as they used the wall; however, this discrepancy may be due to the requirements of each level of the intervention (see Figure 1). Because the intervention required students to use the Notepad on Levels 1 and 3, and only required use of the Wall on Level 2, it is expected that the Notepad would be used more frequently. Participants used the typing feature more often when communicating than any

| Type of Reasoning | Question | Student Answer | Student Explanation | Student Reasoning |
|---|---|---|---|---|
| No attempt at reasoning | 7000/70 | Did not answer | N/A | I don't know, not big on division in my head It's hard for me |
| Guess attempt, incorrect | If 20x15=300, what does 21x15 = | Incorrect (305) | Guessed, did not explain, or gave faulty explanation | Doing it vertical, I knew 5x5=1 and I knew 2x5=10 so you put down your zero |
| Guess attempt, correct | 99+17 | Correct | Used standard algorithm to add | I just added them in my head |
| Partial attempt, reasoning breakdown | 100-18 | Incorrect (81) | Gave other reasonable explanation | When you think about it, it can't be in the 90s because 18 is more than 10, but it can't be in the 100s because you are taking away, so it has to be in the 80s |
| Complete reasoning, calculation error | 99+17 | Incorrect (117) | Used standard algorithm to add | 9+7=16 and you put your 1 by the other 9 and that makes 10 and 10+1 would equal 11 and you put the one in the other place and that makes it 117 |
| Complete reasoning, correct | 99+17 | Correct | Used other method specific to problem | I split the 9 and the 1 up and the equals 10 and I put the 9 in my head and I counted 7 more |
| Entirely wrong process | If 20x15=300, what does 21x15 = | Incorrect (215) | Guessed, did not explain, or gave faulty explanation | I take the 1 away and put the 2 in front of the 15 |

***Figure 2.*** Examples of MRI Responses in Each Category

other combination of tools in both the notepad and when posting on the wall. Communication consisted primarily of documenting information related to mathematical knowledge (e.g., terms, conversions, or facts) followed by mathematical questioning in the notepad and mathematical reasoning for wall posts. Examples of specific participant communication for the notepad and wall can be found in Figure 3. This provides details as to the type of information communicated and how it was recorded within the digital writing environment. Additionally, information was coded for correctness when participants communicated mathematical knowledge, reasoning, or answering; an overwhelming majority of participant documentation was correct (56.2%—notepad; 83.7%—wall). Finally, wall posts were examined when a communication exchange took place between participants to evaluate if the information stayed on topic and more than half of the posts (56.3%) related to one another. Table 2 displays all results of digital environment behavior.

**Reasoning**

Chi-square analyses reveal that participants demonstrated significant changes for all three MRI categories over the course of the intervention (see Figure 4). In the category *student answer*, participants were less likely to answer incorrectly and more likely to either answer correctly or not answer the question at all ($\chi^2$ = 29.794, $df$ = 3, $p$ < .001; ES = .28, $p$ < .001). For *student*

**Table 1**
*Academic and MLC-Related Information*

| Variables | M | SD |
|---|---|---|
| Math Fact Fluency | | |
| Addition | 19.31 | 10.5 |
| Subtraction | 10.73 | 5.5 |
| Multiplication | 12 | 8.24 |
| Oral Reading Fluency | 84.39 | 45.55 |
| Working Memory Composite | 93.08 | 25.46 |
| MLC Pretest | 14.46 | 3.86 |
| MLC Posttest | 16.69 | 5.45 |
| Number of Notepad Entries | 17.31 | 6.76 |
| Number of Wall Posts | 6.38 | 5.49 |
| Entries Per Intervention Level | | |
| Level 1 | | |
| Notepad | 10.31 | 5.60 |
| Wall | N/A | N/A |
| Level 2 | | |
| Notepad | 2.77 | 4.60 |
| Wall | 6.77 | 7.87 |
| Level 3 | | |
| Notepad | 3 | 2.92 |
| Wall | 2.31 | 2.75 |
| Level 4 | | |
| Notepad | 0.85 | 1.28 |
| Wall | 0.54 | 0.78 |

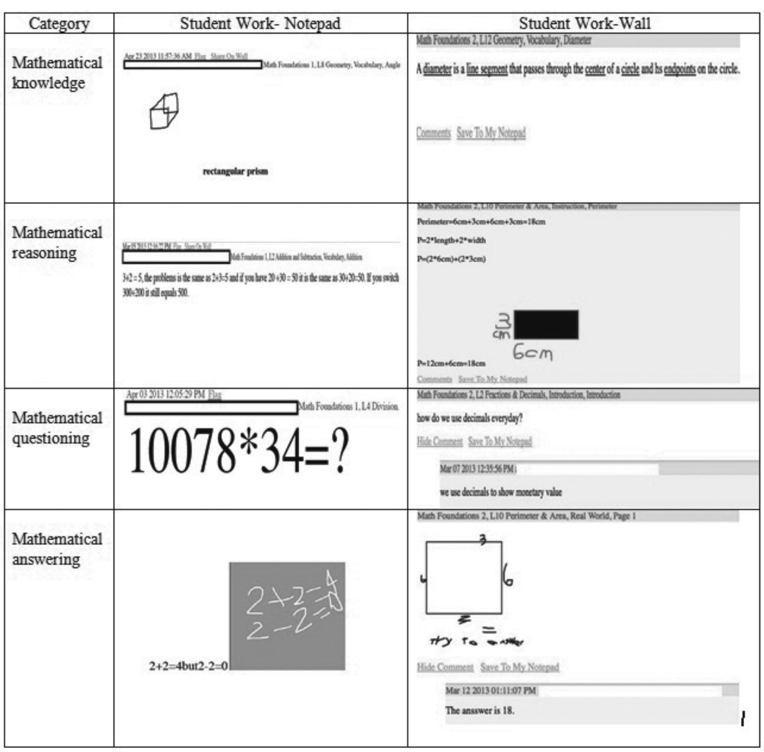


***Figure 3.*** Mathematical Information Student Notepad and Wall Communication Examples.

**Table 2**
*Notepad and Wall Data for All Participants*

| | | Notepad Entry ($n$ = 217) | Wall Entry ($n$ = 126) |
|---|---|---|---|
| **Number of entries** | $M(SD)$ | 17.31(6.76) | 6.38(5.49) |
| **Origin** | $n$(%) | | |
| Notepad-original | | 192(88.5%) | -- |
| Transfer | | 25(11.5%) | -- |
| Wall/self | | 13(6.0%) | -- |
| Wall/peer | | 12(5.5%) | -- |
| Wall/self-original | | -- | 75(59.5%) |
| Comment on own post | | -- | 5(4.0%) |
| Comment on peer's post | | -- | 45(35.7%) |
| **Method of Entry** | | | |
| Typed | | 149(69.3%) | 81(66.9%) |
| Typed & use of symbols | | 19(8.8%) | 18(14.9%) |
| Draw | | 23(10.6%) | 10(8.3%) |
| Type & draw | | 20(9.4%) | 9(7.4%) |
| Type, draw, & symbols | | 4(1.9%) | 3(2.5%) |
| **Content Type** | | | |
| Social | | -- | 17(14.2%) |
| Math | | -- | 86(71.0%) |
| Mix- social, math | | -- | 5(4.1%) |
| Unknown | | -- | 13(10.7%) |
| **Type of Information**[a] | | | |
| Mathematical knowledge | | 149(70.6%) | 31(24.6%) |
| Mathematical reasoning | | 19(9.0%) | 27(21.4%) |
| Mathematical questioning | | 23(10.9%) | 22(17.5%) |
| Mathematical answering | | 20(9.5%) | 8(6.3%) |
| **Mathematically Correct Information**[b] | | | |
| Correct | | 91(56.2%) | 41(83.7%) |
| Partially correct | | 66(40.7%) | 5(10.2%) |
| Incorrect | | 5(3.1%) | 3(6.1%) |
| **Comments**[c] | | | |
| Relates to post | | -- | 27(56.3%) |
| Does not relate to post | | -- | 12(25.0%) |
| Answers a question | | -- | 9(18.7%) |

*Note.* -- indicates this variable was not coded for the item.
[a] Notepad ($n$ = 211) and Wall posts ($n$ = 88) [b]Notepad ($n$ = 162 ) Wall Posts ($n$ = 49 ) [c] Wall post ($n$ = 48)

*explanation*, participants were less likely to guess on the posttest or use the standard algorithm ($\chi^2$ = 32.058, $df$ = 3, $p$ < .001, ES = .32, $p$ < .001). Although they were more likely to use a method specific to the problem or give another reasonable explanation, these differences were not large enough to be significant. Under the category *student reasoning*, participants were more likely to either use complete reasoning and get the answer correct, or show no attempt at reasoning, and they were less likely to guess and get an incorrect answer ($\chi^2$ = 77.109, $df$ = 6, $p$ < .001, ES = .35, $p$ < .001). When taken together, these results indicate a shift in the reasoning of participants from guessing and answering incorrectly to either answering questions correctly or refusing to answer if they do not understand the problem at hand.

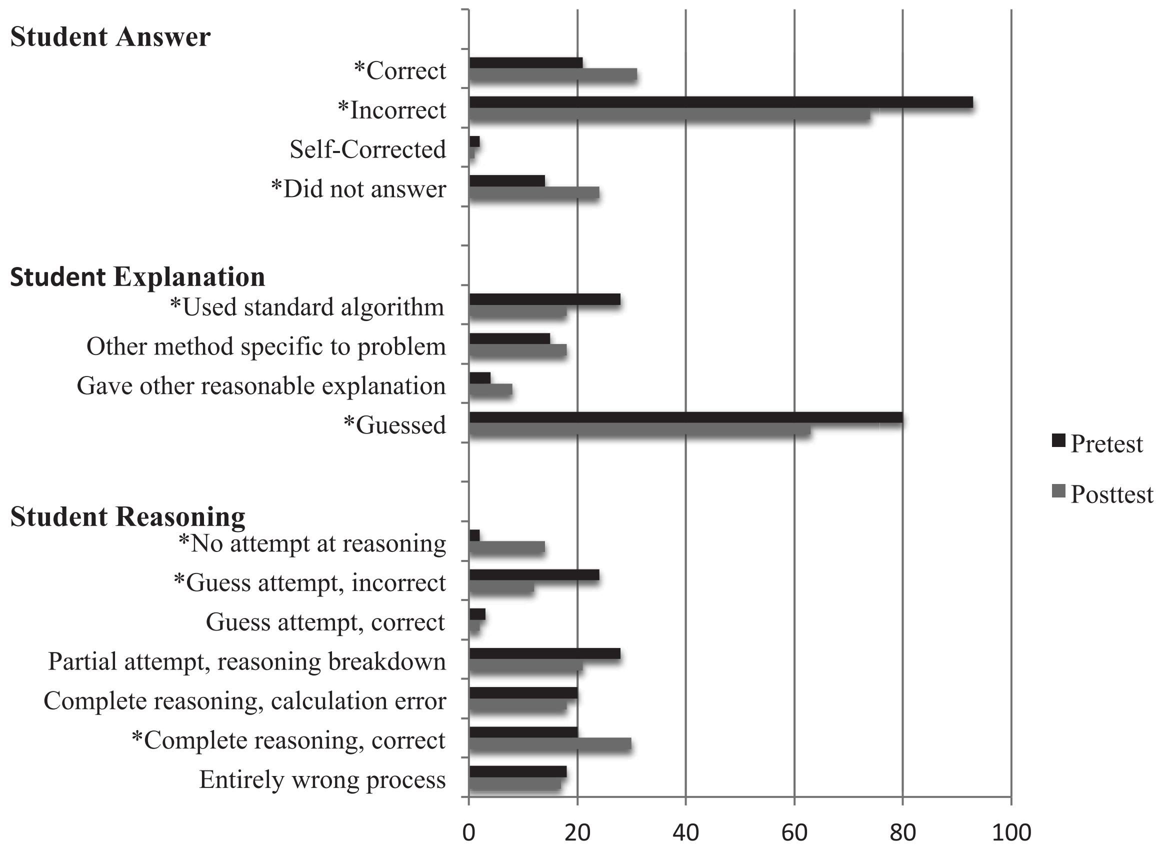


***Figure 4.*** Changes in Mathematical Reasoning from Pretest to Posttest. *Note:* *Reflects differences between the expected and observed frequencies that have a standardized residual > 1.96

## Discussion

Measuring proficiency in mathematics proves problematic when students do not or cannot communicate their mathematical reasoning in a coherent manner. New demands present in the mathematical curricula emphasize students' ability to articulate reasoning. Writing in mathematics offers one way for students to demonstrate reasoning, and technology provides an environment for fostering mathematical communication. Unfortunately, limited research has been conducted regarding the communication of mathematical thinking in a technology-based environment and the effects on mathematical reasoning skills of students with learning disabilities. Therefore, the objectives of this study included understanding how students use a digital writing environment, determining what information they attempt to communicate, and identifying how this may impact mathematical reasoning.

Results indicate that participants demonstrated a change in all three MRI categories (i.e., *student answer, student explanation, student reasoning*). Prior to engaging in the digital-writing environment, participants answered fewer questions correctly, were more likely to guess on answers, use an entirely wrong mathematical process, and provided complete reasoning less often. Given the difficulty that students with learning disabilities have with reasoning (Bressette, 2010), these findings are not surprising; however, they do shed light on how differences in specific reasoning skills manifest themselves. Specifically, the participants had a breakdown in mathematical processes, calculation errors, and used an entirely wrong mathematical process to answer a problem. After using the digital writing environment, participants answered items correctly more often or chose not to answer, used the standard algorithm, or guessed at the answer less often. They were also less likely to guess and get the problem incorrect, more likely to either reason completely through a problem and obtain a correct answer, or not attempt the problem at all than prior to the intervention. The students' ability to select when to answer the problem based on knowing whether or not they can solve the problem shows a possible awareness of a lack of understanding for a given problem that was not present prior to the intervention.

Students did not show statistically significant gains on the MLC pre- to posttest gains; this was not surprising given what is known about the gains of students with learning disabilities relative to typical peers (Friend & Bursuck, 2014; Hocutt, 1996). Notably, all students did make gains from pre/posttest averaging just over two questions correct. Interestingly, students did make statistically significant gains in MRI categories. This may be due to the nature of the measure itself as the MLC pre/posttest was administered via the computer using a multiple choice format whereas the MRI is done verbally and responses were provided orally. By asking participants how they figured out an answer, students were provided with an opportunity to potentially self-correct because as they explain their process it may occur to them an error was made. This brings to light that different formats may lead to different results or possibly that this population in particular may respond in a variety of ways to diverse assessment formats. Finally, the MRI is focused on whole number concepts only, while the MLC pre/posttest focuses on a variety of concepts (e.g., whole numbers, money, geometry); therefore, future studies should consider examining pre/posttest differences for only whole number items.

These findings show similarities to other studies that have examined how communicating mathematical thinking can impact the mathematical reasoning skills of students (Baxter et al., 2005; Burns, 2005; Gadanidis et al., 2011). However, unlike previous research, this study incorporated the use of a digital writing environment instead of traditional paper/pencil communication. Participants were given information on the modalities they could use to communicate, provided with explicit instruction on how and when to record their thoughts within each digital writing environment, and incorporated new writing demands every two lessons. The assimilation of students' reasoning into written assignments and discussions has become an integral part of mathematics teaching (Burns, 2005), and the findings from the current study suggest that communication through a digital writing environment, which includes both a traditional note-taking environment (e.g. the notepad) and use of social interaction (e.g., peer-mediated wall), are useful tools that may foster growth in the mathematical reasoning skills of students with learning disabilities.

Interestingly, participants primarily used both the notepad and the wall to communicate information the research team viewed as mathematical knowledge. Connolly (1989, as cited in Baxter et al., 2005) refers to this as "writing to learn," which may consist of notes, short explanations, draws, or transcribing information (Baxter et al., 2005). Prior research shows that students made gains in academic achievement when "writing to learn" formats are consistently integrated into mathematics learning (Bangert-Drowns, Hurley, & Wilkinson, 2004). Communicating in this way also provides an opportunity for students to make connections between current and prior material, allows for reflection, gain clarification of ideas and associate the various processes involved in math (Cooper, 2012; NCTM, 2000).

Finally, although the intervention only required the wall to be used on Level 2; participants continued to use the wall outside of this parameter. When individual posts were examined, participants used this environment to engage in mathematical conversations with peers that were generally on topic as well as providing correct information to one another. Prior research shows that when students have a purpose for writing that includes an audience, their interest and commitment to a topic increases (Zemelman et al., 2012). Moreover, when a communication exchange occurs students can increase their own knowledge as they engage in discussion and evaluate peers (Gadanisdis et al., 2011; Pearson, 2010; Zemelman et al., 2012). Communicating mathematics through socially based digital writing environments, such as blogs, chats, or forums, has been encouraged and proven beneficial with all students (Zemelman et al., 2012); however, some studies have noted that students with learning disabilities have difficulty with social communication (Mitchell, Franklin, Greco, & Bell, 2009). Intriguingly, the participants in the current study used the social media-based wall for communicating mathematics beyond the requirements of the study. This could be due to a variety of factors, including the students' exposure to social media, age at the time of the study, and the requirement of the study that the students use social media to communicate mathematics on at least one of the four levels.

**Limitations**

Limitations of this study should be acknowledged and addressed in future research. First, the small sample was from two private schools. Because private and public school programs offer various approaches towards mathematics education and online learning, the results and generalizability from this study should be cautiously interpreted as they may not be representative of all elementary students with learning disabilities. Generalizing how writing effects mathematical reasoning skills necessitates replication of this study in other settings and with larger samples. Furthermore, future researchers should consider including a larger and more diverse sample of participants receiving special education services to explore any additional differences among specific categories of students with disabilities. This may help to identify and better understand how to enhance the mathematical skills of students with disabilities.

Second, although the MRI is a validated measure, some of the response categories are subjective in nature and may not provide a comprehensive overview of mathematical reasoning. Specifically, items call for students to complete a problem and state how they arrived at an answer, but students are not allowed to document this process in writing, only through verbal communication. Thus, future studies assessing both the process and product of student's mathematical reasoning might incorporate a modified version of the MRI and allow for students to articulate reasoning through various modes. Third, students in different grade levels did not complete the exact same MLC curriculum, thus different levels of reasoning may have been required within certain lessons. Future studies should consider having students in the same grade complete selected lessons in a systematic order. Furthermore, because the online curriculum is individualized and self-paced, students reached intervention levels at various times. This made it difficult to control for confounding variables such as maturation and teacher instruction. Therefore, it is difficult to say with complete confidence that gains in reasoning were strictly related to the intervention and not because of content teachers chose to focus on in class or length of time in the online program.

**Implications for Practice**

Results reveal that incorporating communication through writing, whether for individual use or social exchange, can be beneficial for students with learning disabilities. Participants in this study communicated various types of mathematical information within the digital writing environment, engaged in social communication with peers about math related topics, and demonstrated improvement in reasoning skills. Although additional research is needed, these findings suggest important implications for practitioners and researchers working to improve the reasoning skills of students with learning disabilities. First, encouraging communication of mathematical thinking by incorporating training on note-taking and recording thoughts or processes positively affects the reasoning skills of students with learning disabilities, providing ideas for teachers to consider when planning mathematics lessons around reasoning. Second, student access to embedded support tools that facilitate communication of mathematical thinking, such as a digital notepad or peer-mediated wall, are beneficial for students and should be considered as an option when learning mathematics. Third, participants used the wall to engage in mathematical conversations, ask questions, and work through problems with peers through written dialogue; therefore, finding ways to facilitate this exchange of mathematical ideas between students is essential. Finally, given that the CCSS (2010) places emphasis on problem solving and reasoning across the eight strands (CCSS, 2010), using measures such as the MRI could be used to better understand the reasoning skills of students with learning disabilities and develop specific goals that could be written into the student's Individualized Education Plan (IEP) related to mathematical reasoning.

Enhancing the problem-solving and reasoning skills of students is integral to mathematics instruction as it continues to be a focus of the educational system in this country. Finding ways to incorporate interventions into mathematics education that promote the development of these skills remains imperative, especially for students with learning disabilities who continue to struggle with reasoning and problem-solving. Placing an emphasis on communication in mathematics through a digital based writing environment proved valuable for students in this study; they showed improvement in different areas of reasoning over the course of the intervention and responded differently to the types of writing environments that were offered. This study demonstrated that incorporating mathematical communication via a digital environment benefited all participants and has the potential to improve mathematics education in general.

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